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Improving Design and Operation of Multiple-Hearth and Fluid Bed Sludge Incinerators

Metcalf and Eddy, Inc., Wakefield, MA

Prepared for

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16. ABSTRACT

The purpose of this investigation is to document improvements in design, operation, and maintenance of multiple-hearth and fluid bed furnace incineration for combustion of sludge in municipal wastewater treatment plants. The information contained in this report is intended to supplement and qualify information available from incinerator manufacturers and published literature. The report addresses incinerator and support systems design deficiencies and solutions, operation and maintenance problems and solutions, fuel efficient operation, upgrading of existing incinerators, administration and personnel training. Advantages and disadvantages of the two types of incinerators in regards to plant size, design, operation, emissions, fuel requirements, maintenance, electric power, and labor are also discussed. Best practices in the areas of operation and maintenance, administration, upgrading, fuel efficiency, emissions, and design of future facilities are also presented. The information for this project was collected from available literature, review of previous surveys of wastewater treatment plants, information from incinerator manufacturers, inhouse experience, site visits to wastewater treatment plants nationwide, and contacts with manufacturers. The data base is included in the appendix.

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IMPROVING DESIGN AND OPERATION OF MULTIPLE-HEARTH AND FLUID BED SLUDGE INCINERATORS

by

Metcalf & Eddy, Inc.
Wakefield, Massachusetts 01880

Contract No. 68-03-3208

Project Officer

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FOREWORD

The U.S. Environmental Protection Agency is charged by Congress with protecting the Nation's land, air, and water systems. Under a mandate of national environmental laws, the agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. The Clean Water Act, the Safe Drinking Water Act, and the Toxics Substances Control Act are three of the major congressional laws that provide the framework for restoring and maintaining the integrity of our Nation's water, for preserving and enhancing the water we drink, and for protecting the environment from toxic substances. These laws direct the EPA to perform research to define our environmental problems, measure the impacts, and search for solutions.

The Water Engineering Research Laboratory is that component of EPA's Research and Development program concerned with preventing, treating, and managing municipal and industrial wastewater discharges; establishing practices to control and remove contaminants from drinking water and to prevent its deterioration during storage and distribution; and assessing the nature and controllability of releases of toxic substances to the air, water, and land from manufacturing processes and subsequent product uses. This publication is one of the products of that research and provides a vital communciation link between the researcher and the user community.

This project was undertaken to document improvements in design, operation, and maintenance of multiple-hearth and fluid bed furnace incineration. The information herein is a compilation of problems and best practices identified during an investigation of these two incinerator technologies based on plant site visits, available literature, manufacturers' data, and design and operation experience.

Francis T. Mayo, Director
Water Engineering Research Laboratory

ABSTRACT

In recent years, improvements in wastewater treatment technology and in the design and operation of wastewater treatment plants have occurred responding to the demand for higher quality effluents. As a result, sludge production has increased. Concurrently, sludge disposal has become more difficult due to more stringent regulations making past disposal methods more costly and limiting current disposal methods. This situation has fostered a renewed interest in sludge incineration technology which greatly reduces the volume of sludge, facilitating sludge disposal and decreasing disposal costs. The purpose of this investigation is to document improvements in design, operation, and maintenance of multiple-hearth and fluid bed furnace incineration for combustion of sludge in municipal wastewater treatment plants.

The information contained in this report is intended to supplement and qualify information available from incinerator manufacturers and published literature. The report addresses incinerator and support systems design deficiencies and solutions, operation and maintenance problems and solutions, fuel efficient operation, upgrading of existing incinerators, administration and personnel training. Advantages and disadvantages of the two types of incinerators in regards to plant size, design, operation, emissions, fuel requirements, maintenance, electric power, and labor are also discussed. Best practices in the areas of operation and maintenance, adminstration, upgrading, fuel efficiency, emissions, and design of future facilities are also presented.

The information for this project was collected from various sources. Available literature and review of previous surveys of wastewater treatment plants established the data base. Information from incinerator manufacturers and inhouse experience updated and supplemented this data base. Site visits to wastewater treatment plants nationwide and contacts with manufacturers provided most of the information regarding incinerator problems, deficiencies, and best practices for successful operation of multiple-hearth and fluid bed furnace incinerators. This project covers a period from June 1984 to June 1985 and work was completed as of September 1985.

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SECTION 1

INTRODUCTION

Improvements in wastewater treatment technology and in the design and operation of wastewater treatment plants are resulting in higher quality effluents with increased sludge production. Concurrently, the problem of sludge disposal has become more difficult due to more stringent regulations making past disposal methods more costly and limiting current disposal methods. Sludge processing and disposal methods that have received only cursory attention in the past are now being reevaluated.

The design, operation, and application of the two sludge processing technologies of multiple-hearth and fluid bed furnace incineration to combustion of sludges in municipal wastewater treatment plants in the United States were investigated. The investigation identified design, operation, and maintenance problems of these technologies and associated sludge processing equipment. An evaluation of the problems and remedial actions that have been or could be employed to alleviate these problems was performed. This report documents the investigation and best practices for successful operation of multiple-hearth and fluid bed furnace incinerators.

Information for this project was collected from various sources including: (1) the available literature, (2) review of information obtained through a previous survey of selected publicly owned treatment works (POTWs), (3) contacts with equipment manufacturers or their representatives or both, (4) contacts and visits to selected POTWs, and (5) the design and operation and maintenance background of Metcalf & Eddy, Inc. in numerous wastewater treatment plants.

The report is organized into six sections. The best practices regarding multiple-hearth and fluid bed incineration identified during this investigation are presented in Section 2. General process descriptions are given in Section 3. The data base used in the investigation is discussed in Section 4. Design, operation, and administrative problems and solutions common to these technologies are presented in Section 5. The last section compares the advantages and disadvantages of the two incinerator technologies.

SECTION 2

BEST PRACTICES

Based upon the problems and practices observed during this investigation, best practices for existing and future incineration systems have been identified. Best practices are discussed in the areas of:

- Operations and maintenance
- Administration and training
- Renovations and upgrading of existing facilities
- Techniques for fuel efficient sludge combustion
- Emissions standards
- Design of future facilities.

OPERATIONS AND MAINTENANCE

Best practices regarding operation and maintenance (O&M) should include procedures to assist in the conservation of auxiliary fuel in multiple-hearth furnaces (MHF) operating in a conventional mode. Improved fluid bed furnace (FBF) operation would also reduce costs. A review of the basic combustion principles is mandatory to achieve successful operation, savings in operating cost, and prolonged utilization of the equipment.

Multiple-Hearth Furnaces

Common operating problems relative to fuel consumption in the MHF are:

- Incinerator exhaust temperatures are too high
- Combustion zone location is too high in the incinerator
- Draft is greater than necessary

- Heated cooling return air is underutilized
- Burner use patterns are not optimal (should use underfire burner, i.e., burners below combustion zone for steady state operation if auxiliary fuel is required).

Assuming that the sludge feed rate and thermodynamic properties of the sludge are not subject to control, there are three primary variables that can be manipulated in a conventional style MHF with all sludge combustion air going to the bottom hearth(s):

- Flowrate of combustion air
- Auxiliary fuel and sludge combustion rate
- Rotational speed of the rabble arms, in revolutions per minute (rpm).

The following parameters must be controlled in the combustion process:

- MHF exhaust temperature (temperature of the uppermost hearth in the absence of a zero hearth or external afterburner)
- Excess air in the MHF exhaust gas
- Temperature of the gas in the combustion zone.

The excess air in the exhaust gas is not measured, but rather the percent of oxygen by volume on a wet or dry basis is measured. Unless otherwise stated, this measurement is on a dry basis. A handy reference formula for converting percent oxygen (dry) to excess air is:

$$\% \text{ XSA} = [O_2/(21 - O_2] \times 100$$

where:

% XSA = Percent excess air

O_2 = Percent oxygen (dry).

The key criteria for MHF sizing and operation are sludge feeding and throughput capacity, furnace heat release, and evaporative capacity. System support equipment vital to the efficient performance of a MHF include:

- A sludge cake feed conveyor system and feeder that provide a steady nonvariable input to the furnace. A live bottom surge bin to regulate the feed would augment the feed system to a large degree.

- Sealed auxiliary fuel burners.

- A well-sealed ash discharge outlet to a wet or dry ash handling system.

- Poke holes located at perimeter drop hole locations.

- Correctly sized burner system blowers and central shaft cooling air fan.

- Central shaft cooling air return ductwork to hearths below the combustion zone.

- An induced draft fan designed with adequate test block capacity to satisfy the desired excess air levels in the furnace with allowances for infiltration and variations in air requirements.

- A venturi scrubber with an impingement tray section.

- An oxygen analyzer to sample flue gases in the breeching from the top hearth of the furnace.

- Temperature measurement in all hearths, and draft measurement in the top hearth and selected points.

- Automatic damper-operated air and gas ducts.

As discussed in this report, the term starved air combustion has been replaced by fuel efficient operation and is applicable to any MHF. MHFs that have been brought to a fuel efficient state and that operate at reduced excess air levels have adopted many of the following procedures:

- Maximum use of central shaft cooling air return

- Low furnace draft measured at the top hearth

- Slow central shaft speed to maximize the drying time

- Combustion of sludge solids at a lower hearth consistent with the number of available hearths in the furnace

- Reduction or elimination of active burners above the combustion zone to make the best use of the drying gases produced in the burning area

- Use of an oxygen analyzer to anticipate combustion occurring in the furnace and control of excess air to reduce heat loss.

Practices to be avoided in operating the MHF are operating the hottest hearth at temperatures where the sludge begins to form clinkers and direct injection of scum and grease into a MHF.

Fluid Bed Furnace

The best practice is to locate both the burner and air entry of a FBF in an external firebox that opens tangentially into the main windbox. The external firebox should contain most of the flame and induce some mixing of the flame and the colder air stream. Consideration should also be given to windbox headroom to avoid impingement and to provide access to the underside of distribution pipes.

In general, the problem of brick arch life is at least as severe in FBFs as in MHFs. FBFs should have slow heating and cooling rates and care should be taken to avoid local hot spots in the furnace.

Control of sludge feeding and combustion air systems in the FBF is more precise than in the MHF. Support systems equipment essential to the performance of the FBF includes:

- Progressive cavity pumps, piston pumps or screw feeders for feeding sludge beneath the surface of the bed

- A fluidizing air blower of multi-stage design

- A preheat burner mounted in the reactor windbox to raise the temperature of the inert bed for the ignition of auxiliary fuel and sludge

- Fuel injectors for direct feed of auxiliary fuel into the bed

- An auxiliary fuel system incorporating flame safeguard controls for burners and a separate reactor fuel injector system

- A reactor freeboard temperature control system, consisting of a high pressure water pump and sprays

- A gas-to-air heat exchanger for hot windbox FBFs

- A venturi scrubber coupled to an impingement tray and demister section.

Basic monitoring actions that should be understood by FBF operators are described below.

Feed Rate. The existing dewatering system will establish the range of sludge feed rates. Operators can observe and monitor two parameters to detect a reduction in sludge feed: a rise in the percent of oxygen in the flue gas and a drop in bed temperature. The operator can respond by increasing sludge feed. The operator can also select an air rate to maintain a desired oxygen content in the flue gas. Sludge, scum or grit should not be fed to the FBF without maintaining the minimum required air flow. Control of scum and grit feed rates should be in a manual mode and scum pumping rates indicated.

Reactor Bed Temperature. Control of the reactor bed temperature is semi-automatic. While constant bed temperature is primarily a function of a uniform sludge feed rate and sludge characteristics, the sludge feed rate can be manually adjusted. If the sludge develops excess heat in the bed, quench water may be added manually or automatically.

In autogenous combustion, the sludge feed and air rates may be adjusted slightly to control bed temperature. However, to maintain bed temperature, sludge combustion may require more heat which may be supplied by auxiliary fuel injected manually into the bed or by hot air from a hot air burner.

Reactor Exhaust Temperature. Automatic operation of high pressure water sprays to maintain the flue gas temperature at the set point are preferred, but the operator may manually control the temperature control system.

Procedures To Reduce Operating Cost

Most municipal sludge incinerator operations are still experiencing high fuel consumption rates as a result of using improper incineration modes. Application of improved operating techniques need to be promoted as a cost-effective approach to reduce incinerator fuel consumption. In addition, comparative analysis of specific fuel consumption with sludge cake moisture and volatile characteristics for various municipal operations needs to be undertaken to exemplify the enormous fuel-saving potential that still exists in many incinerator operations.

ADMINISTRATION AND TRAINING

Several points are critical to good administration of incineration plant operations:

- A clear understanding of the process by supervisors enables monitoring of process trends and detection of inefficiencies. Data collection and documentation procedures should be implemented for process control and optimization, and to ensure compatible operations among sludge handling processes.

- Operators of all sludge handling processes must have an understanding of the interrelationships among the processes, the effects of changes in operation variables, and the importance of communicating changing conditions to operators of other processes.
- Staff training and motivation have a strong impact on process efficiency and cost control of the operation. Efficient incinerator operation requires skilled personnel who have a basic knowledge of the process and who are motivated to develop operating and monitoring procedures that keep costs low.
- Inadequate pay for skilled operators normally results in high turnover that severely affects incinerator efficiency. The costs associated with underskilled operators soon outweigh any dollars saved as a result of low pay.
- Preventive maintenance should be scheduled to maintain planned operating schedules and to minimize downtime and disruption to other sludge processes.
- An inventory of spare parts and supplies should be provided to minimize downtime through proper budget planning and adequate funding.

Operator training is essential for efficient incinerator operation. Incineration is a comparatively sophisticated process that requires knowledge of the interrelationships between sludge characteristics, combustion, process controls, excess air, and auxiliary fuel. Training of personnel responsible for incineration O&M should cover the following:

- Preventive maintenance procedures
- System process control theory and procedures
- Process troubleshooting techniques
- Systems economic considerations
- Process data collection, documentation, and evaluation
- Support systems control, fine tuning, and troubleshooting knowledge.

In future installations, the startup of incinerators and subsystems should be segregated from personnel training activities so that complete online training may be accomplished for any special requirements. Quality training materials should be developed and in-plant personnel should be trained to use these materials in a continuous training effort. An operator certification plan which would train operators and certify them (with better pay scale) similar to the plan that certifies boiler operators would be a good practice.

RENOVATIONS AND UPGRADING OF EXISTING FACILITIES

Technical investigations of conventional MHF operating modes in three major cities, Indianapolis, Indiana, (1); Nashville, Tennessee, (2); and Hartford, Connecticut, (3); and consequent changes in these modes are fully documented in EPA reports on the respective municipal facilities. The analyses performed on furnace operations included both vacuum-filtered and belt press-filtered sludges. The operational modes recommended and adopted, resulted in remarkable savings in auxiliary fuel consumption for all cities. In the case of one city, the operational changes resulted in a large decrease in particulate loading to the scrubbers and the avoidance of back-fitting with new, energy intensive scrubbers at high capital cost

The changes in operation modes for all of these plants include:

- Maximum use of central shaft cooling air return to minimize hot air heat loss
- Reduced draft to minimize air in-leakage
- Slow central shaft speed to increase sludge drying time concurrent with sludge combustion at a selected lower hearth
- Elimination of air flow to and operation of top burners resulting in provision of more hearths for drying at reduced temperatures
- Burner operation under the combustion zone hearths
- Maintenance of excess air at no greater than 50 percent
- Instrumentation and, in some cases, control changes to measure and regulate sludge, air, and fuel flows, and to control fuel and air remotely.

The main thrust of the work performed at the plants in Indianapolis, Nashville, and Hartford is the establishment of operating procedures suited to the sludge feed rate and sludge volatiles, which utilize the MHF volume for combustion in the most appropriate zone and for drying in a far more efficient manner than has been practiced. To achieve fuel savings, the operation has to be performed with greatly reduced excess air. The incinerator upgrading work, resulting from pilot project findings and subsequent recommendations by the Indianapolis Center for Advanced Research (ICFAR) (1) is estimated to have cost $20,000 per incinerator in 1980 to 1981 dollars, which includes operator training. This cost is normally recovered in fuel savings within a 3- to 6-month operating period, since the average savings per furnace is estimated at $180,000 per year.

This approach to incinerator upgrading relies mainly on well trained, informed operators. The inherent strength of the approach is transmitting the full performance capabilities of the furnace to the staff. The capital cost must be considered minimal. The operator training would be invaluable to any municipality based upon the results achieved in the noted cities.

Major renovations to FBF systems are rare in municipal sludge incinerator practice. However, modifications to material handling system components, such as ash handling, sludge feeding, and bed replacement systems, are being made in existing plants. Corrosion and erosion in the exhaust gas outlets and heat exchangers are cause for ongoing maintenance. Such problems appear to have their solution in selection of appropriate high alloy steel and new design approaches to refractory lined carbon steel.

TECHNIQUES FOR FUEL EFFICIENT SLUDGE COMBUSTION

In addition to best practices regarding renovation and upgrading of existing sludge incineration facilities, two active plant operations in the United States are worth noting. A MHF system at San Mateo, California and a retrofitted FBF system at Norwalk, Connecticut are using fuel saving techniques and modifications that can be applied to other systems for efficient sludge combustion.

San Mateo - Multiple-Hearth Furnace

The furnace has an oversized combustion hearth at the approximate midpoint where exhaust gases exit at temperatures of 760 to 870°C (1,400 to 1,600°F). Flue gases from the drying zone of the furnace are recirculated to a single, separately mounted combustion chamber that contains the only auxiliary fuel burner in the system. All fuel burning is completed in this external combustion chamber and the hot gases are introduced into the fixed carbon zone below the combustion zone. Excellent technical features are:

- The ability to utilize the oxygen in the recirculated dried off-gases and the moisture to absorb excess heat in the combustion zone.
- The recirculation gas rate may be varied, for example, to accommodate a decrease in sludge feed solids content by a corresponding increase in gas flow up through the drying zone. By this action, the sludge will reach the combustion zone with the required solids content prior to combustion.
- Excess air is readily controlled.
- The external combustion chamber may be constructed to burn a variety of available fuels, including waste fuels without flame impingement on rabble arms or central shaft. No burners are mounted on the furnace.
- Combustion chamber off-gases have a suitable residence time and temperature for deodorization, and after-burning is not required. A waste heat recovery system does not need to be augmented by after-burning fossil fuel.

A patented recirculation control process is understood to exist for the MHF system and the furnace with all of the features noted is available in the marketplace . The utilization of the MHF at San Mateo, handling sludge with a dry solids content of 25 percent in the startup period, is an excellent example of fuel efficient sludge combustion.

Norwalk - Fluid Bed System

Modifications to a FBF system at a wastewater treatment plant in Norwalk, Connecticut have remarkably increased fuel efficiency compared to the original system, and with a subsequently large increase in sludge throughput and a reduction in manpower. The FBF system, originally installed in 1973, utilized a cold windbox without heat recovery. Sludge was dewatered by centrifuge. Fuel usage was 760 liters (180 gallons) of oil per metric ton of dry solids. The plant was burdened in 1980 with a fuel cost of approximately $500,000 per year for No. 2 fuel oil and a crew of 12 operators.

Presently, the plant superintendent reports that the operating crew has been reduced to four operators with hours of operation reduced from 24 hours per day to 10 hours per day. The fuel oil usage presently varies from 0 to 120 liters (0 to 30 gallons) per metric ton of sludge dry solids. The Norwalk plant superintendent has noted a sludge capacity increase of more than 100 percent, reduction of operating hours by 58 percent, and reduction of manpower by 56 percent from the original system. These improvements are the result of dewatering the sludge by belt press and modifying the FBF system by employing a FBF as a dryer in series with a FBF acting as a combustor. There are two heat exchangers in series and the heat from the combustor FBF is recovered and used to heat the fluidizing air.

The system starts with feeding belt filter pressed sludge directly to the dryer FBF which dries the sludge. The dried sludge and sand from the dryer FBF flows by gravity down to the combustor FBF where the sludge is combusted. A sand lift blower circulates the hot sand from the combustor FBF to the dryer FBF, providing a constantly hot bed for drying. Hot gas, at approximately 810°C (1,500°F), is routed from the combustor FBF through primary and secondary heat exchangers and then through a scrubber to the atmosphere. These heat exchangers preheat fluidizing air to approximately 650°C (1,200°F) and 110°C (230°F) for the combustor and the dryer FBF's, respectively.

The key to fuel savings as the low temperature evaporation in the fluid bed dryer. With less fuel required for evaporating moisture, more air is available to burn sludge.

REVIEW AND PENDING REVISIONS OF STANDARDS OF PERFORMANCE FOR NEW STATIONARY SOURCES - 1984

There is no provision in the existing New Source Performance Standards (NSPS) (40 CFR 60, Subpart O) for monitoring either particulate emissions (through periodic stack testing) or stack opacity for sludge incinerators. As a result of a review of the Standards of Performance for Sewage Sludge Incinerators in 1984, the EPA intends to change the certification process and to require owners and operators of all new, and many existing municipal sludge incinerators, to monitor, record and report specific incinerator input and output data. Metal concentration, moisture content, volatile solids of the sludge feed, as well as fuel usage, are to be identified as input data. Specific metals are to be identified for measurement in the effluent gases as part of particulate emissions. Oxygen measurements at the furnace exit and scrubber pressure drop are also to be monitored and recorded. The agency is also soliciting available data concerning toxic organic emissions from sludge incinerators and will compile a list of identified organic chemicals. Action on implementation of these measurements and the data to be gained indicate the potential for significant improvements in sludge incineration and management.

The EPA review also included discussions on status of control technology and uncontrolled emissions.

Status of Control Technology

Multiple-hearth and fluid bed incinerators operating over the past five years and employing combination venturi/impingement/tray scrubbers are achieving the federal particulate standard of 0.65 gram of particulates per kilogram (1.3 lb/ton) of dry sludge. These scrubbers are operating at an average total pressure drop of 7.5 kN/m^2 (30 inches of water), and many are at 10.0 kN/m^2 (40 inches) or greater.

Uncontrolled rates of particulate emissions from municipal sludge incinerators are highly variable and efforts are being made to correlate these emissions with improved incinerator operating practices. The efficiency of particulate scrubbers in removing potentially toxic trace elements from the flue gases is generally less than that for total particulates. There is no apparent correlation between the pressure drop of the control devices and their corresponding removal efficiencies for trace elements.

The history of scrubber application in municipal sludge incineration has been successful, particularly the combination venturi/impingement tray type. Only a small percentage of scrubbers (20 percent) on MHFs were installed with the venturi/impingement tray combination before 1978. After 1978, emissions from most newly installed incinerators equipped with the combination scrubbers are well under the NSPS limit.

Uncontrolled Emissions from Municipal Sludge Incinerators

Uncontrolled emissions from both MHFs and FBFs are extremely variable. Electric incinerators appear to have the lowest rates of uncontrolled particulates. Data on uncontrolled emissions from all furnaces are limited and are not normally available because measurements at the scrubber inlet or the furnace outlet are infrequent.

Relationships between operating parameters and uncontrolled emission rates are discussed in the EPA review in a qualitative manner. Characteristics of sludge feed, such as moisture and volatile contents, both of which affect auxiliary fuel input, are responsible for high air flow. Higher air flowrates increase particulate entrainment. Low volatile solids and high inerts also contribute to uncontrolled particulates. Other operating conditions and practices that affect uncontrolled emissions as discussed in the EPA review are:

- Multiple-hearth furnace ash drop chutes not properly sealed

- High excess air rates

- Excessive sludge feed rates
- Rabble arm speed
- Combustion zone location
- Burner use profile
- Combustion air flow geometry.

The beneficial impact of operational changes and modifications instituted in Indianapolis incinerators by the ICFAR are noted particularly in relation to particulate emission reduction. Particulate emissions at Indianapolis are reported to have decreased by approximately 70 percent from the levels before operational changes were made.

DESIGN OF FUTURE FACILITIES

The first and most important step for the design of a municipal sludge incineration system is to define the sludge feed and to establish the parameters required for the furnace and auxiliary systems. The two basic design criteria to be formulated for sludge feed are:

- Feed rate, in kilograms of wet cake per hour
- Properties of the feed:
  - Percent solids (preferable to moisture content)
  - Percent combustibles in the solids (total volatiles)
  - Gross heating value of the combustibles
  - Ultimate analysis of combustibles
  - Presence of chemicals that react endothermically.

The softening and fusion points of the ash, determined by ASTM Method D-1857-68, are also highly desirable. These criteria can be determined if a valid specimen of the sludge or ash can be obtained.

In many instances, these criteria are not known with precision before specifications are prepared. The designer depends upon the accumulation of in-house data concerning sludge feed characteristics. Ranges of expected values are reviewed to assure that the furnace will meet the needs of the wastewater treatment plant.

An effective alternative to specifying wide ranges in sludge feed and properties is to specify cases representing different possible modes of plant operation to develop the above criteria and heat and material balances. Once these criteria are developed, then minimum and maximum furnace exhaust temperatures, and minimum and maximum percent oxygen (excess air) in the exhaust gas can be determined.

Before specifications are finalized, heat and material balances should be revised and finalized for each case, and a table should be prepared indicating the following:

- Sludge combustion air required, mass flowrate and volume rate, in kilograms per hour and standard cubic meters per minute
    - Shaft cooling air recycle (if a MHF is considered)
    - Ambient air temperature
- Auxiliary fuel required in kJ per hour, or in fuel volume terms, and fuel analysis and characteristics
- Auxiliary fuel combustion air required, in kilograms per hour and standard cubic meters per minute
- Furnace exhaust flue gas volume, in actual cubic meters per minute.

After this table of values is completed, a summary table indicating the minimum and maximum values for each of the above parameters should be prepared. This table should then be examined to determine whether the turndown of the individual equipment items is within the useful and feasible operating range of the equipment.

A single safety factor applied to the quantity of sludge to be processed should be the overall safety factor. This procedure will result in a design where all components of the system are sized to handle a reasonable contingency.

SECTION 3

OVERVIEW OF SLUDGE INCINERATION

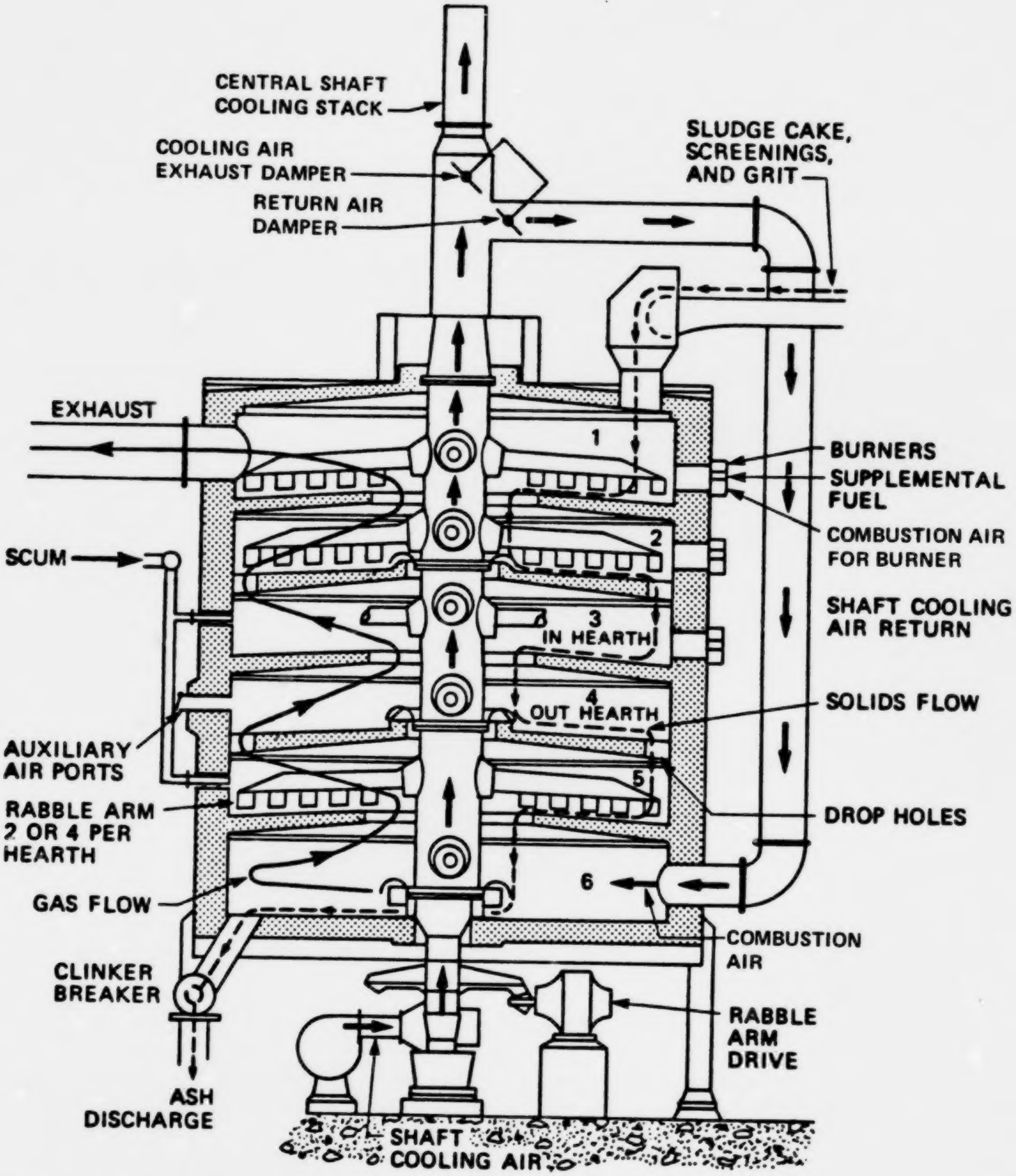
There are several types of sludge incineration systems. The two most commonly used systems today are the multiple-hearth furnace and the fluid bed furnace. Complete descriptions of systems are in the U.S. Environmental Protection Agency publication entitled "Process Design Manual: Sludge Treatment and Disposal", EPA 625/1-79-011, 1975.

MULTIPLE-HEARTH FURNACE

The multiple-hearth furnace is the most widely used incinerator for combustion of municipal sludge. Currently, over 350 wastewater treatment plants nationwide have MHFs. Multiple units occur in many of these plants.

The MHF is durable and relatively simple to operate if sludge feed quality and rate are constant. This type of incinerator can handle wide variations in sludge characteristics and loading rates if such variations are experienced over the long range such as month to month, but hour to hour variations present combustion and operational difficulties. The MHF is best suited to continuous operation. Intermittent MHF operation is unadvisable unless the furnace temperature is maintained at "hot standby" (about 430°C) due to startup fuel requirements and the time required to bring the hearths and internal equipment from a completely cold condition to operating temperature.

A cross-section of a MHF is shown in Figure 1. The furnace consists of a circular steel shell with a series of horizontal hearths made of fire bricks. The rotating central shaft is a hollow iron column cast in sections. The shaft is normally insulated and suitable for temperatures about 430°C (800°F) for continuous operation and 590°C (1,100°F) short term operation. Shaft speeds are adjustable and are normally 1/2 to 2 revolutions per minute (rpm). Dewatered sludge is fed into the furnace at the top hearth and proceeds downward through the furnace from hearth to hearth moved by rotating rabble arms attached to the central shaft. The arms are normally 25 percent


CENTRAL SHAFT
COOLING STACK
COOLING AIR
EXHAUST DAMPER
RETURN AIR
DAMPER
SLUDGE CAKE,
SCREENINGS,
AND GRIT
EXHAUST
1
2
3
IN HEARTH
4
OUT HEARTH
5
6
BURNERS
SUPPLEMENTAL
FUEL
COMBUSTION AIR
FOR BURNER
SHAFT COOLING
AIR RETURN
SOLIDS FLOW
DROP HOLES
SCUM
AUXILIARY
AIR PORTS
RABBLE ARM
2 OR 4 PER
HEARTH
GAS FLOW
CLINKER
BREAKER
COMBUSTION
AIR
RABBLE
ARM
DRIVE
ASH
DISCHARGE
SHAFT
COOLING AIR

SOURCE: U. S. EPA PROCESS DESIGN MANUAL FOR
SLUDGE TREATMENT & DISPOSAL
EPA 625/1-79-011

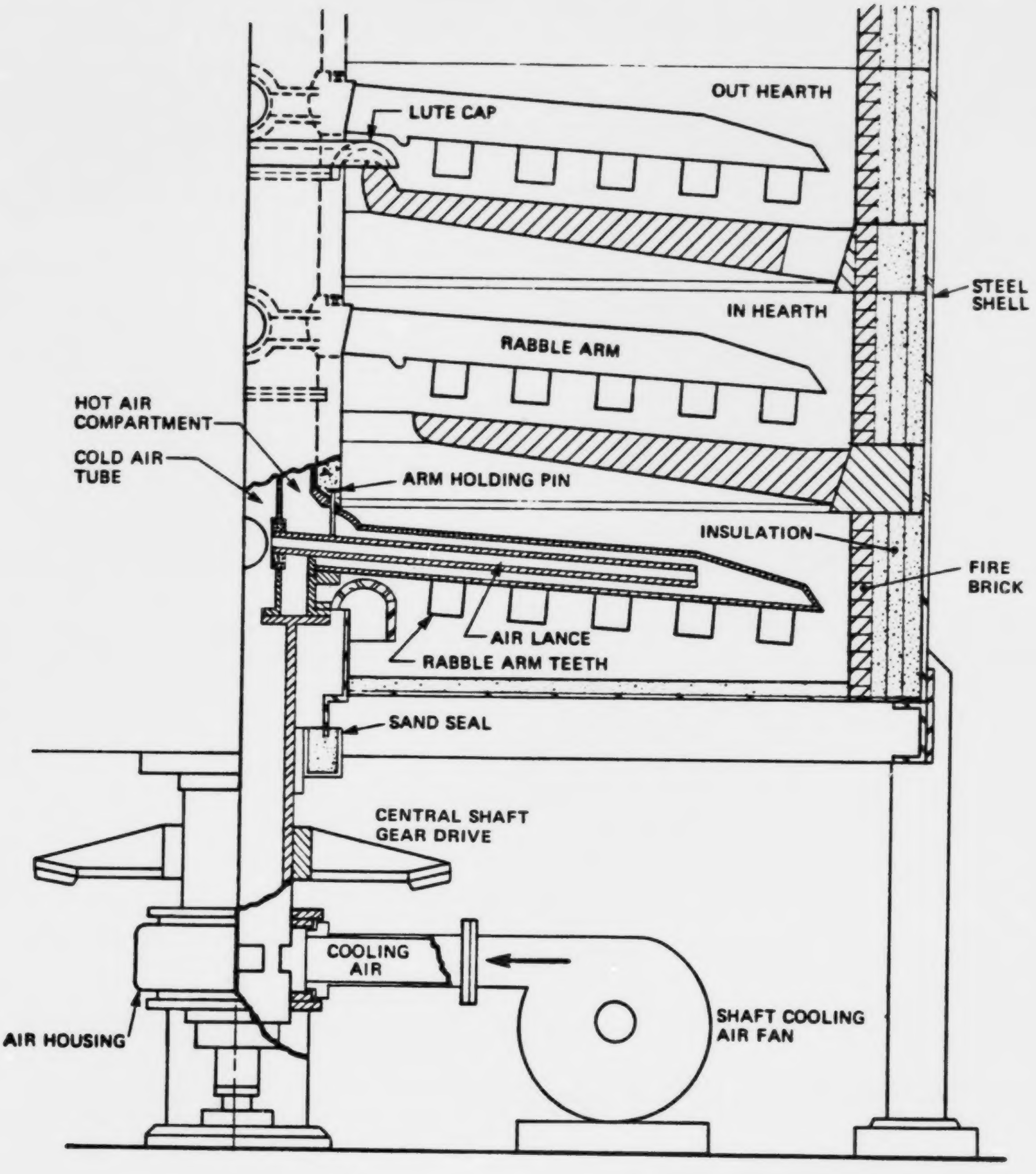
FIGURE 1. CROSS SECTION OF A MULTIPLE-HEARTH FURNACE

chrome, 12 percent nickel alloy castings. The rabble arms constantly move the sludge in the hearths aiding drying and burning. Ash is discharged from the bottom of the furnace, and gas and exhaust air are discharged from the top.

Air is supplied to cool the shaft and rabble arms and for combustion. A cold air tube runs up the center of the shaft and air lances extend from the tube to the end of each rabble arm as seen in Figure 2. Ambient air is blown through the cold air tube and lances. The cold air exits from the lance tips, flowing back to the annular space in the shaft through the space between the lances and the rabble arm wall . This flow of air cools the shaft and rabble arms by convection. The central shaft cooling air is discharged to the atmosphere via the exhaust gas stack, returned to the bottom hearth of the furnace, or both, if only a portion of this heated air is needed for sludge combustion. The heated air may also be used for direct forced warm air heating of the furnace area, because this air is uncontaminated due to air leakage outward from the central shaft to the furnace.

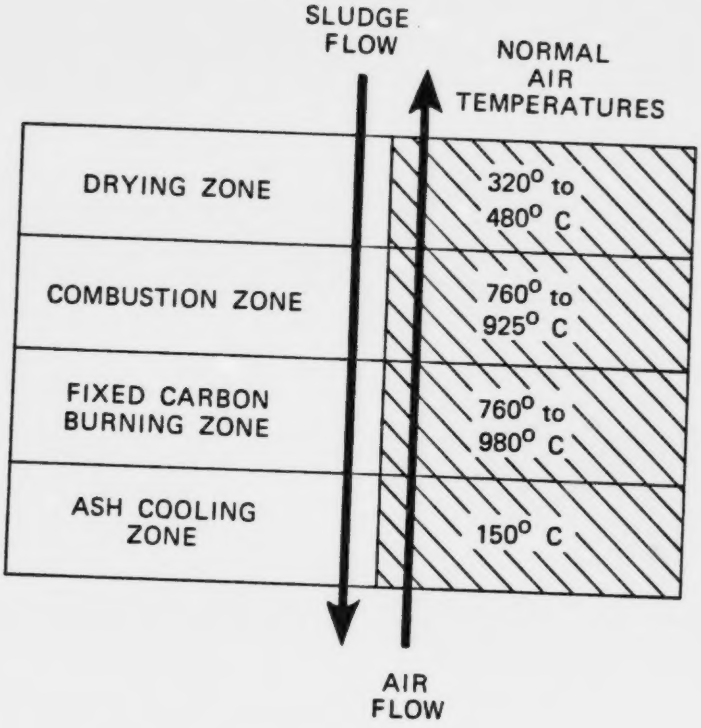
The functions of drying the wet feed, combusting sludge volatiles, complete burning of fixed carbon, and cooling ash are performed in distinct zones of the furnace from top to bottom as seen in Figure 3. The first zone (drying zone) consists of the upper hearths where heated combustion gases flow upward countercurrent to the descending sludge, drying and heating the sludge. The second zone (combustion zone) generally consists of the central hearths. In this zone, the majority of volatile organics are burned and some of the fixed carbon in the sludge begins combustion; temperatures reach 760 to 925°C (1,400 to 1,700°F). In the third zone (fixed carbon burning zone), the burning of the fixed carbon continues and is completed. Ash is cooled and discharged from the fourth zone utilizing returned central shaft air for cooling. The sequence of these zones is always the same, but the number of hearths employed in each zone is dependent on the quality of the feed, and the design of the furnace and burner system. Drying and combustion may occur on the same hearth in some instances.

Furnace gases exit from the MHF at temperatures ranging from 320 to 480°C (600 to 900°F) in normal operation without afterburning. At some sites, air emissions standards and sludge characteristics require an afterburner to raise the temperature of the exhaust gases to 760°C (1,400°F) or higher to destroy odor causing constituents and burnout of hydrocarbons. Afterburners may either be inside the top of the furnace or outside the furnace. The status of emission control technology applied to sludge incineration and the 1984 review of the Standards of Performance for New Stationary Sources is discussed in Section 2.


OUT HEARTH
LUTE CAP
STEEL SHELL
IN HEARTH
RABBLE ARM
HOT AIR COMPARTMENT
COLD AIR TUBE
ARM HOLDING PIN
INSULATION
FIRE BRICK
AIR LANCE
RABBLE ARM TEETH
SAND SEAL
CENTRAL SHAFT GEAR DRIVE
COOLING AIR
SHAFT COOLING AIR FAN
AIR HOUSING

SOURCE: U. S. EPA PROCESS DESIGN MANUAL FOR
SLUDGE TREATMENT & DISPOSAL
EPA 625/1-79-011

FIGURE 2. INTERIOR CUTAWAY VIEW OF A MULTIPLE-HEARTH FURNACE


SLUDGE FLOW
NORMAL AIR TEMPERATURES
DRYING ZONE
320° to 480° C
COMBUSTION ZONE
760° to 925° C
FIXED CARBON BURNING ZONE
760° to 980° C
ASH COOLING ZONE
150° C
AIR FLOW

SOURCE: U. S. EPA PROCESS DESIGN MANUAL FOR
SLUDGE TREATMENT & DISPOSAL
EPA 625/1-79-011 (MODIFIED)

FIGURE 3. PROCESS ZONES IN A MULTIPLE-HEARTH FURNANCE

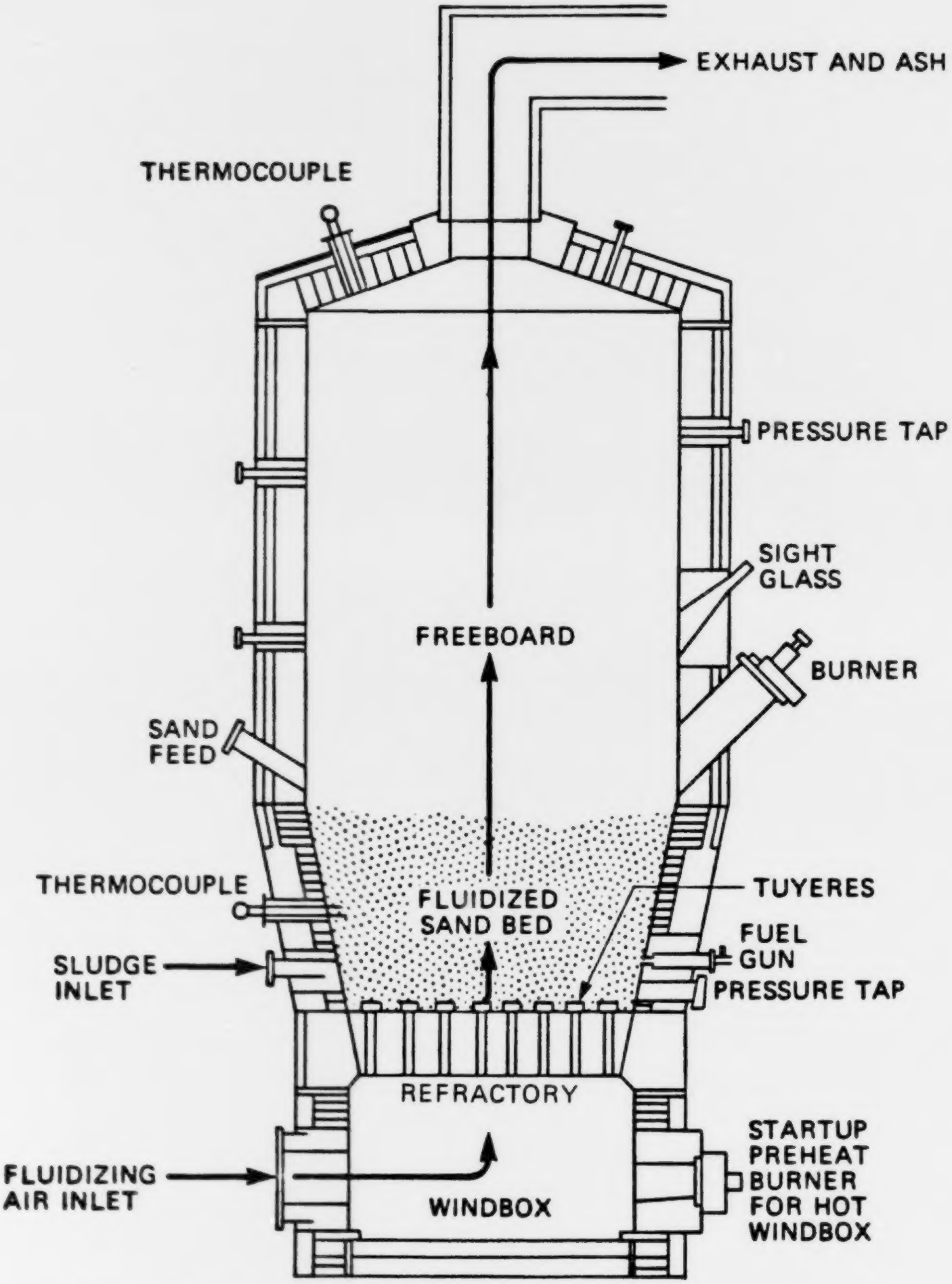
Generally, the heating value of the sludge is insufficient to sustain autogenous combustion and additional heat is provided by adding supplemental fossil fuel to the MHF. Auxiliary fuel burners are located at selected hearth levels in the furnace, normally below the combustion zone hearth. Burners may operate either continuously or intermittently on selected hearths to maintain temperatures best suited to the sludge feed.FLUID BED FURNACE

Municipal sludge incineration with fluid bed furnaces has increased over recent years. Currently, about 60 wastewater treatment plants in the U.S. have FBFs.

The fluid bed furnace, seen in Figure 4, is a vertical cylindrically-shaped, refractory-lined steel shell that contains a sand bed (media) and fluidizing air orifices to produce and sustain combustion. The FBF is normally available from 2.7 to 7.6 meters (9 to 25 feet) in diameter. The sand bed is approximately 0.8 meters (2.5 feet) thick when quiescent, resting on a brick dome or refractory-lined grid. The sand bed support area contains orifices, commonly known as tuyeres, through which air is injected into the furnace at a pressure of 20 to 35 kN/m^2 gage (3 to 5 psig) to fluidize the bed. The mass of suspended solids and gas, when active and at operating temperature, expands to approximately double the at-rest volume. Sludge is quickly mixed within the fluid bed by the turbulent action of the bed. Evaporation of the water and combustion of the sludge solids rapidly takes place. Combustion gases and ash leave the bed and are transported through the freeboard area to the gas outlet at the top of the furnace. Combustion gases and entrained ash are scrubbed, normally in a venturi scrubber. In some designs, the exhaust gases pass through a gas-to-air heat exchanger to preheat the fluidizing air. A flowsheet for a FBF system is shown in Figure 5.

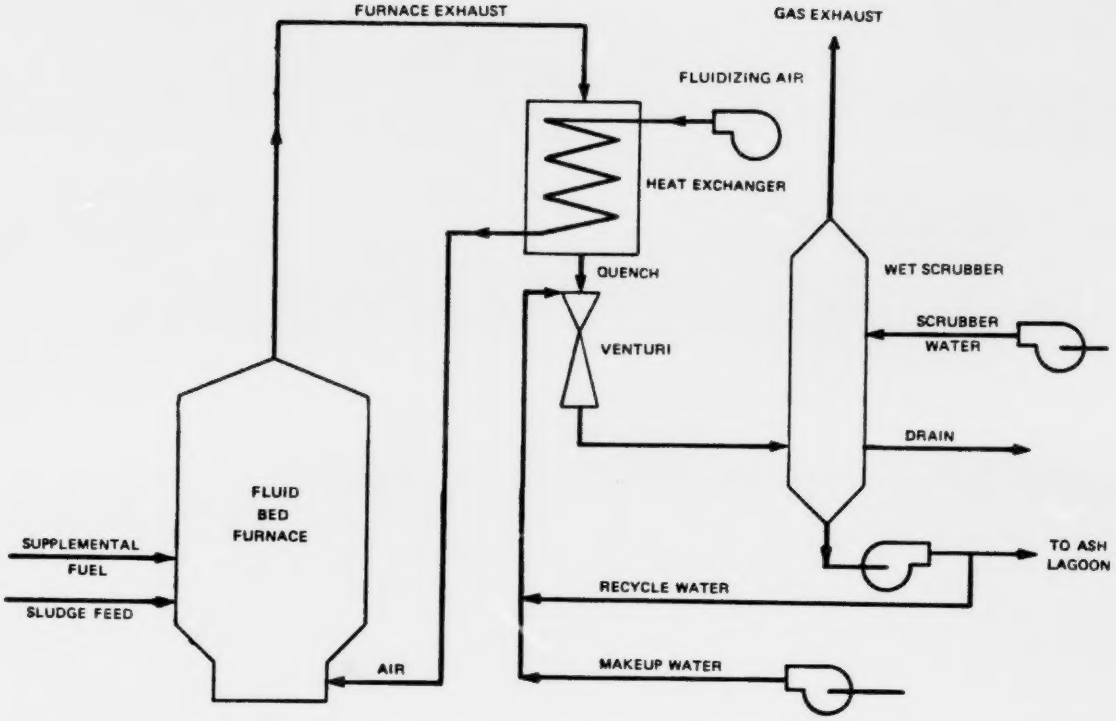
The water and combustible content of the sludge normally establishes the heat demand in the bed once air flow is set. Fuel is injected into the sand bed as required to maintain bed temperature or to heat the fluidizing air. Auxiliary burners may be located either above or below the sand bed. In some installations, a water spray in the freeboard area or a heat-removal system in the bed controls furnace temperature.

Both drying and combustion of sludge occur primarily within the fluidized sand bed. The minimum temperature needed in the sand bed prior to injection of sludge is approximately 700°C (1,300°F). The temperature of the sand bed is controlled between 760 and 820° (1,400 and 1,500° F). Gas residence time is approximately 5 to 10 seconds.


EXHAUST AND ASH
THERMOCOUPLE
PRESSURE TAP
SIGHT GLASS
FREEBOARD
BURNER
SAND FEED
THERMOCOUPLE
FLUIDIZED SAND BED
TUYERES
FUEL GUN
SLUDGE INLET
PRESSURE TAP
REFRACTORY
STARTUP PREHEAT BURNER FOR HOT WINDBOX
FLUIDIZING AIR INLET
WINDBOX

SOURCE: U. S. EPA PROCESS DESIGN MANUAL FOR
SLUDGE TREATMENT & DISPOSAL
EPA 625/1-79-011

FIGURE 4. CROSS SECTION OF A FLUID BED FURNACE


FURNACE EXHAUST
GAS EXHAUST
FLUIDIZING AIR
HEAT EXCHANGER
QUENCH
WET SCRUBBER
VENTURI
SCRUBBER WATER
DRAIN
FLUID BED FURNACE
SUPPLEMENTAL FUEL
SLUDGE FEED
TO ASH LAGOON
RECYCLE WATER
AIR
MAKEUP WATER

SOURCE: U. S. EPA PROCESS DESIGN MANUAL FOR
SLUDGE TREATMENT & DISPOSAL
EPA 625/1-79-011

FIGURE 5. FLOW SHEET FOR SLUDGE INCINERATION IN A FLUID BED FURNACE

The freeboard space above the expanded sand bed is designed to allow disengagement of entrained sand particles. Sand or other bed media not disengaged in the freeboard zone passes out of the bed with the ash, and must be periodically replaced. Media losses are reported to be approximately 5 percent of the design bed volume for every 300 hours of operation. Replacement media are introduced to the furnace either above or directly into the bed.

Combustion of gases and entrained sludge solids continues in the freeboard area after separation from the bed, and adequate detention time and volume must be provided to complete this combustion prior to exhaust. Freeboard combustion may be observed by noting the increase in temperature measured between the bed and the freeboard thermocouple. Up to 5 percent of the total furnace heat release may occur in the freeboard area. Freeboard combustion in excess of 5 percent may result in incompletely burned organics passing through the exhaust system.

Effective destruction of organic substances that might cause odorous exhaust gases are provided by 90 to 98 percent complete combustion within the expanded sand bed, adequate freeboard volume with an overall residence time of 5 to 10 seconds, and a temperature ranging from 760 to 870°C (1,400 to 1,600°F). Because the exhaust gases are maintained at these temperatures for the above time in normal FBF operation, unburned hydrocarbon emissions are minimal, and strict hydrocarbon regulations can be met without using an afterburner. However, operating conditions must be proper and steady to assure a low level of emissions at all times.

Sufficient air for combustion in a FBF is provided such that the sludge organics plus fuel will not consume more than about 85 percent of the oxygen in the air supply, leaving 15 percent excess. To account for imperfect mixing in the combustion zone, the FBF is typically designed with 30 to 45 percent excess air capacity to ensure adequate oxygen is available. Less excess air capacity may result in incomplete combustion.

This air supply may either be fed at ambient temperature (cold windbox) or heated (hot windbox). In cold windbox design, the fluidizing air is not preheated. The support beneath the sand bed serves as the air distribution plate and is constructed of metal. This metal plate is designed for temperatures up to 540°C (1,000°F) or slightly higher. Provisions for plate expansion at much higher temperatures require greater design attention and cost.

In hot windbox design, the air can be heated by burners within the windbox or by a heat exchanger that captures heat from the high temperature exhaust of the furnace. The hot windbox unit utilizes a refractory brick dome bed beneath the sand. This construction is somewhat similar to the refractory hearths of MHF's. The brick domes are often twice as thick as MHF's hearth cross-sections, however, since they support the sand bed and the air pressure for fluidization. Large, specially shaped bricks in the dome are pierced by holes 2.5 to 7.6 cm (1 to 3 inches) in diameter, through which metal air nozzles are placed, forming the tuyeres for injection of the fluidizing air.

The fluid bed acts as a thermal sink providing substantial heat storage capacity. This capacity dampens temperature fluctuations that may result from short term variations in sludge feed properties and feed rates. To indicate the heat storage characteristics of a FBF, a bed suitable for combustion at a rate of 6,300,300 kJ/hr (6,000,000 Btu/hr) would absorb or release about 105,500 kJ (100,000 Btu) to change the expanded bed area temperature by 12°C (20°F) including the media bed, refractory dome bed support, and refractory walls. This heat storage capacity also enables relatively quick startups if the shutdown period has been short, e.g., overnight, and protects the refractory dome and support arches from cracking by dampening out thermal cycling.

SECTION 4

GENERAL BASELINE DATA

This section describes the data base developed during this investigation and contains some general conclusions drawn from analysis of the data. At the end of this section, tables listing plants with incineration facilities are provided, categorized according to types of furnaces, dewatering equipment, and waste heat recovery. A table listing sludge mass and moisture contents for those incinerator facilities where information was available is also provided. The section concludes with a summary of information on facilities visited during this investigation.

DESCRIPTION OF DATA BASE

The data base for this investigation was collected from the following sources:

- 1982 EPA Needs Survey, 1982 (4) listings for plants containing the following categories of equipment:

Wet air oxidation equipment	(Code 99)
Multiple-hearth furnace(s)	(Code B2)
Fluid bed furnace(s)	(Code B3)

- Data collected by Metcalf & Eddy, Inc.

- Manufacturers' installation lists from:

Fluid bed	Multiple-hearth
Dorr-Oliver	Neptune-Nichols
Bethlehem	Bethlehem
Copeland	BSP-Envirotech
	Zimpro

- Draft EPA publication entitled "Municipal Sludge Combustion," July 1984 (5).

- Information on selected POTWs, collected under EPA Contract No. 68-03-3019 (6).

Information was assembled using the following data categories for each plant recorded:

- Wastewater treatment plant name and location
- Descriptive codes for components of sludge handling train (key contained in Table 3)
  - type(s) of sludge handled (primary, digested, waste activated)
  - type(s) of incinerator (fluid bed, multiple-hearth)
  - type(s) of dewatering equipment (vacuum filter,centrifuge, filter press)
  - type(s) of sludge conditioning (polymer, chemical, or thermal)*
  - waste heat recovery (waste heat boiler, hot wind-box, or unspecified type)
- Wastewater treatment plant design flow and most recently reported operating flow, in m^3/d
- Incinerator operating status (operating, nonoperating, intermittent operation)
- Startup date for incinerator(s)
- Sludge conditioning (specific thermal conditioning equipment or chemicals, where applicable)
- Sludge dewatering (specific equipment, where applicable)
- Hours per week of operation of incinerator(s)
- Dry solids incinerated, in kg/hr. Where available, this means actual operating condition; otherwise, design condition.
- Percent dry solids incinerated. Where available, actual operating percent; otherwise, design value.

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* Thermal conditioning as used in this report refers to heat treatment or wet air oxidation (low, medium, or high pressure). Chemical conditioning refers to use of lime and/or ferric chloride and does not include use of polymer.

- Wet mass, in kg/hr. Where available, based on actual operating condition; otherwise, design value.

The data base was initially developed using the 1982 EPA Needs Survey data. These data were then cross-checked and updated against data in the 1984 EPA publication entitled "Municipal Sludge Combustion" (5). Additional cross-checking was done between the 1982 Needs Survey data for multiple-hearth and fluid bed incinerators and the data for wet air oxidation (4). Cross-checking was also done to determine if multiple listings for the same wastewater treatment plant appeared under different names, i.e., city, county, plant name, discharge body of water, etc. A final cross-check was done against manufacturers' installation lists and other available information. Any plant which was listed in one source and not elsewhere, and did not appear to be a plant already listed under a different name, was added to the data base. All information gaps have been filled wherever possible with the best available information.

While the data base contains sufficiently accurate information to make some reasonable generalizations, the following limitations regarding specific pieces of information should be recognized:

- Much of the available data did not include numbers or sizes of incinerators, dewatering equipment, or thermal conditioning equipment.

- Much of the available data on plants using filter presses did not specify the type of presses i.e., belt filter presses vs. recessed plate filter presses.

- Many of the plants surveyed did not report quantities of sludge incinerated or solids contents. Where this information was not available from the Needs Survey, the information was taken from manufacturers' installation lists. The manufacturers' installation lists give design capacity and solids contents, but not actual operating conditions. The usefulness of this design information is limited in regards to drawing conclusions concerning actual operation.

- Many of the plants surveyed did not report dewatering methods. Generalizations can only be made for those plants where this data were reported.

- No data were available concerning the use of afterburners. This topic was not addressed in this investigation.

- Some incorrect listings may exist in the data base, since individual verification of all data was not possible.

Due to the limits of the data base, the number of MHF and FBF units in each wastewater treatment plant listed is unknown. The number of incinerator facilities in this report refers to the number of treatment plants that are reported to have MHF or FBF incineration.

OVERALL ASSESSMENT OF INSTALLATIONS

Most of sludge incineration facilities currently operating in the United States are MHFs; MHFs outnumber FBFs about eight to one. In recent years, an increasing number of FBFs have been applied to sludge incineration. The fluid bed incineration technology has matured in the last 15 years, whereas the technology of multiple-hearth incineration has been in use for more than 40 years.

The majority of sludge incineration facilities in the United States are in the Northeast, Great Lakes area, and Central and Northern Atlantic states. The geographic distribution of plants with incineration facilities in the United States divided by EPA regions is indicated in Table 1. Most new incinerator facility construction has been limited to larger capacity wastewater treatment plants (greater than 38,000 m^3/d); most shutdowns or abandonments have been at smaller plants.

The data base indicates a total of 411 wastewater treatment plants have either MHF or FBF sludge incinerators. Of these, 352 plants or 86 percent have MHFs, and 60 plants or 15 percent have FBFs. One plant was reported to have both types of furnaces. Of the multiple-hearth facilities, 271 plants or 77 percent were reported to be operating, at least intermittently. Of the fluid bed facilities, 29 plants or 48 percent were reported to be operating.

Sludge dewatering for both types of incinerators is commonly done with vacuum filters, centrifuges, and/or filter presses. Dewatering by vacuum filters predominates at existing plants. Where centrifuges are used, polymer addition is used almost universally for sludge conditioning. A minority of plants use filter presses (either belt or recessed plate filter presses), in many cases with polymer or chemical sludge conditioning. Generally lime and ferric chloride are used to chemically condition the sludge before dewatering; thermal conditioning is also used.

TABLE 1. DISTRIBUTION OF MULTIPLE-HEARTH AND FLUID BED INCINERATORS

EPA Region No.	Number of MHF Facilities*	Number of FBF Facilities*	Total Number of Incineration Facilities
1	41	6	47
2	88	16	104
3	60	10	70
4	25	3	28
5	70	4	74
6	12*	3*	14
7	20	6	26
8	8	0	8
9	21	10	31
10	7	2	9
Totals	352	60	411

* Totals include New Orleans, LA East Bank Plant which has both multiple hearth and fluid bed units.

Sludge mass incineration data is available for 64 plants in the data base. Recorded fluid bed incineration rates are plant totals and range from 160 to 2,700 kg/hr (350 to 6,038 lbs/hr) of dry solids. Sludge feed solids concentrations at these installations range from 21.0 to 40.0 percent. The average FBF plant incineration rate calculated from data for nine facilities is 1,040 kg/hr (2,271 lbs/hr), at an average solids concentration of 32.4 percent. Based on these figures and an estimate of operating units, an estimate of the total fluid bed incineration rate nationwide is about 30,000 kg/hr (66,000 lbs/hr) of dry solids.

Multiple-hearth incineration rates (plant totals) range from 30 to 19,000 kg/hr (61 to 42,000 lbs/hr) of dry solids. Reported sludge feed concentrations range from 4.0 to 50.0 percent, although the concentrations reported for four facilities at less than 10 percent are dubious. The average MHF plant incineration rate calculated from this data for 55 facilities is 1,750 dry kg/hr (3,850 lbs/hr), at an average solids concentration of 28.2 percent. Based on these figures, an estimate of the total multiple-hearth incineration rate nationwide is 612,400 dry kg/hr (1.35×10^6 lbs/hr) of dry solids, or roughly 20 times the total rate for fluid bed incineration.

Operating incineration facilities, grouped by type of furnace and dewatering equipment, are listed in Table 2. The abbreviations are the same as those used in the complete alphabetical listing of incinerator facilities in the appendix. Key abbreviations and explanations are listed in Table 3.

Operating incineration facilities with waste heat recovery, grouped by type of furnace and waste heat recovery, are listed in Table 4.

Operating incineration facilities where sludge mass incineration data were available are listed in Table 5.

A compilation of numbers and percentages of each type of operating incineration facility, grouped by dewatering methods and sludge conditioning, is listed in Table 6. The numbers and percentages in this table do not account for those facilities where dewatering methods were not reported.

A compilation of numbers and percentages for each type of operating incineration facility, listed by type of waste heat recovery, is shown in Table 7. The percentages are based on the assumption that those facilities that did not report waste heat recovery do not have waste heat recovery.

SITE VISITS TO OPERATING FACILITIES

As part of the data collection phase of this investigation, existing plants using multiple-hearth and fluid bed furnaces were visited. The information collected during these visits included identification of design and operating problems, attempted remedial actions, and operational experiences. A data summary of the plants visited is provided in Table 8.

TABLE 2. NUMERICAL BREAKDOWN OF DATA BY TYPE OF INCINERATOR AND DEWATERING EQUIPMENT

CITY	STATE	PLANT NAME	SLUDGE	INCINERATOR	DEWATERING	CONDITIONING
PLANTS WITH FLUID BED INCINERATORS (TOTAL NUMBER = 29)						
S. BAYSIDE	CA			FBI		
SAN BERNARDINO	CA	WWTF NO. 2	PWD	FBI		TC
HAZLETON	PA		PW	FBI		
CLARKSVILLE	TN		PW	FBI		
BLACKSBURG	VA	LR STRAUBLES CK		FBI		
EDMONDS	WA		P	FBI		
FBI WITH UNIDENTIFIED METHOD OF DEWATERING = 6						
N LITTLE ROCK	AR	FAULKNER LADE	P	FBI	C	PC
NORWALK	CT		PW	FBI	C	TC
SO WINDSOR	CT		P	FBI	C	PC
KANSAS CITY	KS	KAW PT.	P	FBI	C	PC
KANSAS CITY	KS	NO. 20	PWD	FBI	C	PC
CHURCHTON	MD	BROADWATER WWTP ANNE ARUNDEL CY		FBI	C	PC
PT HURON	MI		PW	FBI	C	PCTC
PT WASHINGTON	NY		P	FBI	C	PC
FBI WITH CENTRIFUGES = 8						
REDWOOD CITY	CA			FBI	FP	CC
DUBUQUE	IA		P	FBI	FP	PCTC
SOUTH DOWNS	NY	ERIE CTY	W	FBI	FP	CC
WATERTOWN	NY			FBI	FP	CC
FBI WITH FILTER PRESSES = 4						
OCEAN CITY	MD		P	FBI	VF	PC
DULUTH	MN	WLSSD REGL		FBI	VF	
INDEPENDENCE	MO	ROCK CREEK	PW	FBI	VF	TC
JEFFERSON CITY	MO		P	FBI	VF	
SHELBY	NC			FBI	VF	
ELMA CENTER	NY	ELMA MDWS SUBD		FBI	VF	
MARION	NY	MARION SAN SS		FBI	VF	
PT BYRON	NY			FBI	VF	
HARLEYSVILLE	PA			FBI	VF	
NORTH WALES	PA	UPR GWYNEDD TWP	PW	FBI	VF	
FBI WITH VACUUM FILTERS = 10						
HAMBURG	NY	SOUTHTOWNS SD3	PW	FBI	VFC	PC
FBI WITH VACUUM FILTER AND CENTRIFUGE = 1						

TABLE 2. (CONTINUED)

CITY	STATE	PLANT NAME	SLUDGE	INCINERATOR	DEWATERING	CONDITIONING
PLANTS WITH MULTIPLE HEARTH FURNACES (TOTAL NUMBER = 272)						
MARTINEZ	CA	CTL CNTRA CSTA		MH		
NAUGATUCK	CT		PS	MH		
NEW LONDON	CT		PS	MH		
WILMINGTON	DE	DE RECL PROJ		MH		
DECATUR	IL			MH		
ELKART	IN			MH		
INDIANAPOLIS	IN	BELMONT ST #1		MH		
LENEXA	KS	LITTLE MILL CRK		MH		
QUINCY	MA	NUT IS		MH		
BALTIMORE	MD	PISCATAWAY		MH		
ANN ARBOR	MI	YPSI COMMUNITY		MH		
CHELSEA	MI			MH		
ESSEXVILLE	MI	ESSEXVILLE		MH		
TRENTON	MI			MH		
WYANDOTTE	MI	WAYNE CTY	P	MH		
CAPE GIRARDEAU	MO			MH		
MONROE CITY	MO			MH		
NATCHEZ	MS			MH		
BUTTE	MT	SILVER BOW CTY		MH		
PLATTSMOUTH	NB			MH		
ROCKY MT.	NC			MH		
GOFFSTOWN	NH			MH		
ASBURY PARK	NJ			MH		
DEAL	NJ	DEAL BOROUGH		MH		
FREEHOLD	NJ	FREEHOLD BORO		MH		
HOBOKEN	NJ			MH		
LINDEN	NJ	LINDEN ROSELLE		MH		
MARLBORO	NJ	CENTRAL JERSEY		MH		
MAYS LANDING	NJ			MH		
NEPTUNE	NJ	S MONMOUTH REG		MH		
NEW PROVIDENCE	NJ			MH		
PARSIPPANY	NJ	TROY HILLS	P	MH		
SAYREVILLE	NJ			MH		
SECAUCUS	NJ			MH		
SOUTH KEARNY	NJ	KEARNY IND		MH		
DOUGLAS CITY	NV	ZEPHYR COVE SID #1		MH		
CAMILLUS	NY			MH		
FISHKILL	NY	BROCKWAY SSA #3		MH		
LAWRENCE	NY			MH		
LIBERTY	NY		P	MH		
LIMA	NY			MH		
NEWBURGH	NY	COLDEN PARK SD		MH		
OSSINING	NY			MH		
PLEASANT VALLEY	NY	NOXON KNOLLS SD		MH		
PLEASANT VALLEY	NY	TITUSVILLE SD		MH		
RETSOF	NY	RETSOF SD		MH		

TABLE 2. (CONTINUED)

CITY	STATE	PLANT NAME	SLUDGE	INCINERATOR	DEWATERING	CONDITIONING
SOUTHAMPTON	NY	DISP DISTR 15		MH		
WOODLAWN	NY	WOODLAWN SD		MH		
LORAIN	OH	BLACK RIVER		MH		
MIDDLEBURG HTS	OH			MH		
MINERAL RIDGE	OH	MEANDER CREEK		MH		
WILLOUGHBY	OH	WILL'BY EASTLK		MH		
OKLAHOMA CITY	OK	N CANADIAN		MH		
BETHLEHEM	PA			MH		
BRIDGEPORT	PA		P	MH		
DURYEA	PA	LWR LACKAWANNA	P	MH		
FARRELL	PA			MH		
JOHNSTOWN	PA	JOHNSTOWN		MH		
CRANSTON	RI			MH		
NASHVILLE	TN	WHITES CREEK		MH		
ALEXANDRIA	VA	ALEX SAN AUTH		MH		
MONTGOMERY	WI			MH		
SMITHERS	WI			MH		
ABERDEEN	WV			MH		
MT VERNON	WV			MH		
MUKILTEO	WV			MH		
ST MARYS	WV			MH		
MH WITH UNIDENTIFIED METHOD OF DEWATERING = 67						
CONWAY	AR	STONE DAM		MH	C	PC
PALO ALTO	CA	PALO ALTO REGL		MH	C	PC
S. LAKE TAHOE	CA	S. TAHOE		MH	C	PC
SACRAMENTO	CA			MH	C	
GROTON	CT		PW	MH	C	PCTC
ATLANTA	GA	R.M. CLAYTON		MH	C	PC
HONOLULU	HI	HONOULIULI		MH	C	PCTC
HONOLULU	HI	SAND IS		MH	C	PCTC
LAKE CHARLES	LA	PLANT B		MH	C	PC
LAKE CHARLES	LA	PLANT C		MH	C	PC
METAIRIE	LA	W. NAPOLEON #1		MH	C	PC
NEW BEDFORD	MA		P	MH	C	PC
WORCESTER	MA	UPR BLACKSTN RG		MH	C	PC
ANNAPOLIS	MD	ANNE ARUNDEL CY		MH	C	PCTC
BALTIMORE	MD	COX CREEK ANNE ARUNDEL CY	PW	MH	C	TC
WASHINGTON	MD	WESTERN BRANCH UPPER MARLBORO	PW	MH	C	PCTC
LEBANON	NH		PW	MH	C	PC
MANCHESTER	NH	MANCHESTER WWTF		MH	C	PC
ATLANTIC CITY	NJ	ATLANTIC CY REG		MH	C	TC
BERKELEY	NJ	CENTRAL		MH	C	PC
BRIDGEWATER	NJ	SOMST-RARITAN		MH	C	PC
TOMS RIVER	NJ	SOUTHERN		MH	C	PC
UNION BEACH	NJ	BAYSHORE REGL		MH	C	PC
GREECE	NY	N W QUADRANT TP		MH	C, VF, BFP	PC
OLEAN	NY			MH	C	PC
POUGHKEEPSIE	NY		PW	MH	C	TC
UTICA	NY	ONEIDA CTY		MH	C	PC
CLEVELAND	OH	WESTERLY NE OHIO REGL		MH	C	PC

TABLE 2. (CONTINUED)

CITY	STATE	PLANT NAME	SLUDGE	INCINERATOR	DEWATERING	CONDITIONING
TIGARD	OR	DURHAM REGL	W	MH	C	PC
CAMP HILL	PA	LWR ALLEN TWP	PW	MH	C	
COLUMBIA	SC	METROPOLITAN	PW	MH	C	
NEWPORT NEWS	VA	BOAT HARBOR		MH	C	PC
NORFOLK	VA	ARMY BASE		MH	C	PC
VA BEACH	VA	CHESAPEAKE-ELIZ HAMPTON RDS.		MH	C	TC
WOODBRIDGE	VA	POTOMAC RIVER		MH	C	PC
BELLINGHAM	WV			MH	C	PC
MH WITH CENTRIFUGES = 36						
SKAGWAY	AK			MH	FP	
TRUCKEE	CA	TAHOE-TRUCKEE		MH	FP	
STRATFORD	CT			MH	FP	PC
DECATUR	GA	POLE BRIDGE		MH	FP	
JONESBORO	GA	R.L. JACKSON		MH	FP	
SAVANNAH	GA	PRESIDENT ST	PW	MH	FP	
SMYRNA	GA	CHATTAHOOCHEE COBB CTY	PW	MH	FP	
SMYRNA	GA	R.L. SUTTON		MH	FP	
ATTLEBORO	MA		PW	MH	FP	
FALL RIVER	MA			MH	FP	PC
BALTIMORE	MD	PATAPSCO WWTP	P	MH	FP	CC
ANN ARBOR	MI	CY OF ANN ARBOR		MH	FP	CC
OWOSSO	MI			MH	FP	
ST CHARLES	MO	ST CHAS MS RIV		MH	FP	
PRINCETON	NJ	SBRSA #1		MH	FP	PC
BUFFALO	NY	BIRDS IS	PW	MH	FP	PC
LEMOYNE	PA	BORO OF LEMOYNE		MH	FP	PC
IRVING	UT	CENTRAL		MH	FP	
BROOKFIELD	WI	FOX RIVER	PW	MH	FP	
DE PERE	WI		S	MH	FP	
MH WITH FILTER PRESSES = 20						
ANCHORAGE	AK	PT WORONZOF	P	MH	VF	
GIRDWOOD	AK			MH	VF	
CASTRO VLY	CA	ORO LOMA SD		MH	VF	
LAKE ARROWHEAD	CA			MH	VF	
SAN CLEMENTE	CA			MH	VF	
SAN MATEO	CA			MH	VF	TC
YOSEMITE NTL PK	CA		PW	MH	VF	
AVON	CO	UPR EAGLE VLY		MH	VF	
LAKEWOOD	CO	S. LAKEWOOD		MH	VF	
VAIL	CO			MH	VF	
CROMWELL	CT	MATTABASSETT		MH	VF	
KILLINGLY	CT		PS	MH	VF	
NEW HAVEN	CT	EAST ST		MH	VF	
SIMSBURY	CT			MH	VF	
STAFFORD	CT		PW	MH	VF	
THOMPSONVILLE	CT	ENFIELD		MH	VF	
VERNON	CT	ROCKVILLE		MH	VF	

TABLE 2. (CONTINUED)

CITY	STATE	PLANT NAME	SLUDGE	INCINERATOR	DEWATERING	CONDITIONING
WATERBURY	CT		PW	MH	VF	
ATLANTA	GA	UTOY CREEK	PD	MH	VF	
DECATUR	GA	SNAPFINGER CR	PW	MH	VF	
LOVEJOY	GA	SHOAL CREEK		MH	VF	
CEDAR RAPIDS	IA		PW	MH	VF	TC
DAVENPORT	IA		PW	MH	VF	TC
SIOUX CITY	IA			MH	VF	
MISHAWAKA	IL			MH	VF	
EAST CHICAGO	IN			MH	VF	
OVERLAND PK	KS	INDIAN CK MD BS		MH	VF	
SHAWNEE MSN	KS	TURKEY CRK #1 JOHNSON CTY WD	PW	MH	VF	
NEW ORLEANS	LA	WEST BANK		MH	VF	
CHICOPEE	MA		PW	MH	VF	
FITCHBURG	MA	EAST		MH	VF	
PERRYMAN	MD	SOD RUN		MH	VF	TC
ROCKLAND	ME			MH	VF	
BAYCITY	MI			MH	VF	CC
DETROIT	MI			MH	VF	
E. LANSING	MI		PW	MH	VF	
FLINT	MI	MONTROSE DST 2		MH	VF	
GRAND RAPIDS	MI		PW	MH	VF	TC
KALAMAZOO	MI		PW	MH	VF	TC
NILES	MI	NILES WWTP		MH	VF	TC
PONTIAC	MI	PONT SEW TRT DV	D	MH	VF	CC
SAGINAW	MI			MH	VF	
EAGAN	MN	SENECA		MH	VF	CC
KANSAS CITY	MO	BIG BLUE RIVER		MH	VF	
ST LOUIS	MO	BISSELL PT	P	MH	VF	
ST LOUIS	MO	LEMAY	P	MH	VF	
GREENSBORO	NC	N BUFFALO		MH	VF	
CONCORD	NH	WRB LACONIA		MH	VF	
MERRIMACK	NH	MERRIMACK WWTP		MH	VF	
NASHUA	NH			MH	VF	
BAYONNE	NJ			MH	VF	
CEDAR GROVE	NJ			MH	VF	
CINNAMINSON	NJ			MH	VF	
ELIZABETH	NJ	JT MEET		MH	VF	
JERSEY CITY	NJ	WEST SIDE		MH	VF	
LIVINGSTON	NJ			MH	VF	
MEDFORD	NJ			MH	VF	
MEDFORD LAKES	NJ			MH	VF	TC
MOUNT HOLLY	NJ	RANCOCAS ROAD		MH	VF	
NEWTON	NJ			MH	VF	TC
PALMYRA	NJ	PALMYRA BORO		MH	VF	TC
STANHOPE	NJ	MUSCONETCONG		MH	VF	
TOTOWA	NJ	RIVERVIEW DRIVE		MH	VF	
WAYNE	NJ	MT VIEW WPCP		MH	VF	PC
ALBANY	NY	NORTH	PW	MH	VF	
ALBANY	NY	SOUTH		MH	VF	
BEACON	NY		PWD	MH	VF	
CELORON	NY	S CHAUTAUQUA LK		MH	VF	
DUNKIRK	NY	DUNKIRK STP	PS	MH	VF	CC
HALFMOON	NY	SARATOGA CSD1		MH	VF	

TABLE 2. (CONTINUED)

CITY	STATE	PLANT NAME	SLUDGE	INCINERATOR	DEWATERING	CONDITIONING
MAMARONECK	NY			MH	VF	
MENANDS	NY	NORTH ALBANY		MH	VF	
NEW ROCHELLE	NY	WESTCHESTER CTY	PW	MH	VF	TC
ORANGEBURG	NY	ORANGETOWN DPW		MH	VF	PC
OSWEGO	NY	EAST SIDE		MH	VF	
OSWEGO	NY	WEST SIDE		MH	VF	PC
POUGHKEEPSIE	NY	ARLINGTON SD		MH	VF	
PT CHESTER	NY			MH	VF	TC
ROCHESTER	NY	F E VAN LARE		MH	BPP	
ROCHESTER	NY	GATES CHILI OGD		MH	VF	
SCHENECTADY	NY			MH	VF	
SUFFERN	NY	SUFFERN VILLAGE		MH	VF	
SUFFOLK CO.	NY			MH	VF	TC
SYLVAN BEACH	NY	E ONEIDA LAKE		MH	VF	
TONAWANDA	NY	2 MI CREEK 2	PW	MH	VF	TC
TROY	NY	RENSSELEAR CSD1		MH	VF	
W. BABYLON	NY	SOUTHWEST SD #3		MH	VF	TC
AKRON	OH			MH	VF	
CANTON	OH		PWD	MH	VF	TC
CINCINATTI	OH	LITTLE MIAMI	PW	MH	VF	TC
CINCINNATI	OH	MILL CREEK WWTP		MH	VF	PCTC
CINCINNATI	OH	MUDDY CREEK	PW	MH	VF	TC
CLEVELAND	OH	SOUTHERLY	PW	MH	VF	TC
COLUMBUS	OH	JACKSON PIKE #1	PWD	MH	VF	PCTC
COLUMBUS	OH	JACKSON PIKE #2		MH	VF	TC
COLUMBUS	OH	SOUTHERLY	PWD	MH	VF	TC
EUCLID	OH			MH	VF	
MASSILLON	OH			MH	VF	TC
MIDDLETOWN	OH			MH	VF	
WARREN	OH			MH	VF	
YOUNGSTOWN	OH		P	MH	VF	
ABINGTON	PA			MH	VF	
AMBRIDGE	PA			MH	VF	
APOLLO	PA	KISKI VLY WPCA	P	MH	VF	
CHESTER	PA	DELCORA CHESTER	PW	MH	VF	
COLMAR	PA	HATFIELD TWNP	P	MH	VF	TC
ERIE	PA	ERIE CITY	PW	MH	VF	
HARRISBURG	PA			MH	VF	TC
JOHNSTOWN	PA		P	MH	VF	
KING OF PRUSSIA	PA	TROUT RUN		MH	VF	
LANSDALE	PA	UPP GWYN-TOW	P	MH	VF	
MCKEESPORT	PA			MH	VF	
NORRISTOWN	PA	E NORTWN PLYMTH	PS	MH	VF	
OLD FORGE	PA	LWR LACKAWANNA		MH	VF	
PHOENIXVILLE	PA	VALLEY FORGE		MH	VF	TC
PITTSBURGH	PA	ALCOSAN		MH	VF	PCCC
SCRANTON	PA	SCRANTON SA		MH	VF	
W HAZELTON	PA	GR HAZELTON JSA		MH	VF	
WILKES-BARRE	PA	WYOMING VLY SA	P	MH	VF	
WILLOW GROVE	PA	U MORELD-HTBORO		MH	VF	

TABLE 2. (CONCLUDED)

CITY	STATE	PLANT NAME	SLUDGE	INCINERATOR	DEWATERING	CONDITIONING
YORK	PA	YORK WPC CTR		MH	VF	PCTC
WOONSOCKET	RI		PW	MH	VF	
CHARLESTON	SC	PLUM IS	P	MH	VF	
BRISTOL	TN	GALLOWAY MILL	PW	MH	VF	
MARYVILLE	TN	MARYVILLE REGL	PWD	MH	VF	
NASHVILLE	TN	NASHVLE CENTRAL		MH	VF	
NEWPORT	TN		P	MH	VF	PC
HOUSTON	TX	ALMEDA SIMS		MH	VF	TC
PLANO	UT	PLANO-ROWLTT CR		MH	VF	
FAIRFAX	VA	LWR POTOMAC	PW	MH	VF	
HOPEWELL	VA	HOPEWL REG AUTH	PW	MH	VF	TC
LORTON	VA	LOWER POTOMAC		MH	VF	CC
NORFOLK	VA	LAMBERTS POINT		MH	VF	
WILLIAMSBURG	VA			MH	VF	
GREEN BAY	WI	GREEN BAY MSD	PW	MH	VF	TC
MILWAUKEE	WI	JONES IS		MH	VF	
CLARKSBURG	WV		PW	MH	VF	PC
EDMONDS	WV			MH	VF	
LONGVIEW	WV			MH	VF	
VANCOUVER	WV	WESTSIDE		MH	VF	
WHEELING	WV			MH	VF	
MH WITH VACUUM FILTERS = 141						
NEW HAVEN	CT	EAST SHORE	PW	MH	VFC	PCTC
PENSACOLA	FL	MAIN ST		MH	VFC	PC
DETROIT	MI	WYANDOTTE		MH	VFC	PC
AMHERST	NY		W	MH	VFC	
GREENVILLE	UT			MH	VFC	PC
MH WITH VACUUM FILTERS AND CENTRIFUGES = 5						
HARTFORD	CT		PW	MH	VFFP	
N. ANDOVER	MA	GRTR LWRNCE SD		MH	VFFP	
MINNPLS-ST PAUL	MN	METROPOLITAN	PWD	MH	VFFP	PCTC
MH WITH VACUUM FILTERS AND FILTER PRESSES = 3						
PLANT WITH MULTIPLE HEARTH FURNACE AND FLUID BED INCINERATOR (TOTAL NUMBER = 1)						
NEW ORLEANS	LA	EAST BANK		MHFB	C	PC
MHFB WITH CENTRIFUGE = 1						

TABLE 3. ABBREVIATION KEY

Type of Sludge Incinerated

P	Primary
W	Waste Activated
D	Digested

Type of Incinerator

MH	Multiple-hearth Furnace
FBI	Fluid Bed Incinerator
MHFB	Multiple-hearth Furnace and Fluid Bed Incinerator

Type of Sludge Dewatering

C	Centrifuge
VF	Vacuum Filter
FP	Filter Press

Type of Sludge Conditioning

TC	Thermal Conditioning
CC	Chemical Conditioning
PC	Polymer Conditioning

Waste Heat Recovery

WHR	Waste Heat Recovery System (Unspecified Type)
WHB	Waste Heat Boiler
HWB	Hot Windbox
NWHR	No Waste Heat Recovery System

Operating Status

OP	Operating
N	Not in Operation
IOP	Intermittent Operation

TABLE 4. NUMERICAL BREAKDOWN OF DATA BY TYPE OF INCINERATOR AND WASTE HEAT RECOVERY

CITY	STATE	PLANT NAME	SLUDGE	INCINERATOR	DEWATERING	WASTE HEAT RECOVERY
NUMBER OF PLANTS WITH NO WASTE HEAT RECOVERY = 52						
NUMBER OF PLANTS ON WHICH NO WASTE HEAT RECOVERY INFORMATION WAS AVAILABLE = 203						
PLANTS WITH FLUID BED INCINERATORS (TOTAL NUMBER = 14)						
REDWOOD CITY	CA			FBI	FP	HWB
WATERTOWN	NY			FBI	FP	HWB
FBI WITH HOT WIND BOXES = 2						
N LITTLE ROCK	AR	FAULKNER LADE	P	FBI	C	WHB
DUBUQUE	IA		P	FBI	FP	WHB
KANSAS CITY	KS	KAW PT.	P	FBI	C	WHB
KANSAS CITY	KS	NO. 20	PWD	FBI	C	WHB
DULUTH	MN	WLSSD REGL		FBI	VF	WHB
SHELBY	NC			FBI	VF	WHB
SOUTH DOWNS	NY	EIRIE CTY	W	FBI	FP	WHB
HAZLETON	PA		PW	FBI		WHB
CLARKSVILLE	TN		PW	FBI		WHB
FBI WITH WASTE HEAT BOILERS = 9						
S. BAYSIDE	CA			FBI		WHR
NORWALK	CT		PW	FBI	C	WHR
HAMBURG	NY	SOUTHTOWNS SD3	PW	FBI	VFC	WHR
FBI WITH UNSPECIFIED METHOD OF WASTE HEAT RECOVERY = 3						
PLANTS WITH MULTIPLE HEARTH INCINERATORS (TOTAL NUMBER = 33)						
SACRAMENTO	CA			MH	C	WHB
SAN MATEO	CA			MH	VF	WHB
HONOLULU	HI	HONOULIULI		MH	C	WHB
HONOLULU	HI	SAND IS		MH	C	WHB
CEDAR RAPIDS	IA		PW	MH	VF	WHB
DAVENPORT	IA		PW	MH	VF	WHB

TABLE 4. (CONCLUDED)

CITY	STATE	PLANT NAME	SLUDGE	INCINERATOR	DEWATERING	WASTE HEAT RECOVERY
ANN ARBOR	MI	CY OF ANN ARBOR		MH	FP	WHB
GRAND RAPIDS	MI		PW	MH	VF	WHB
KALAMAZOO	MI		PW	MH	VF	WHB
NILES	MI	NILES WWTP		MH	VF	WHB
MINNPLS-ST PAUL	MN	METROPOLITAN	PWD	MH	VFFP	WHB
ATLANTIC CITY	NJ	ATLANTIC CY REG		MH	C	WHB
BUFFALO	NY	BIRDS IS	PW	MH	FP	WHB
NEW ROCHELLE	NY	WESTCHESTER CTY	PW	MH	VF	WHB
SUFFOLK CO.	NY			MH	VF	WHB
TONAWANDA	NY	2 MI CREEK 2	PW	MH	VF	WHB
CLEVELAND	OH	SOUTHERLY	PW	MH	VF	WHB
ERIE	PA	ERIE CITY	PW	MH	VF	WHB
PITTSBURGH	PA	ALCOSAN		MH	VF	WHB
YORK	PA	YORK WPC CTR		MH	VF	WHB
HOPEWELL	VA	HOPEWL REG AUTH	PW	MH	VF	WHB
VA BEACH	VA	CHESAPEAKE-ELIZ HAMPTON RDS.		MH	C	WHB
GREEN BAY	WI	GREEN BAY MSD	PW	MH	VF	WHB
	MH WITH WASTE HEAT BOILERS = 23					
ANCHORAGE	AK	PT WORONZOF	P	MH	VF	WHR
S. LAKE TAHOE	CA	S. TAHOE		MH	C	WHR
ATTLEBORO	MA		PW	MH	FP	WHR
ANN ARBOR	MI	YPSI COMMUNITY		MH		WHR
E. LANSING	MI		PW	MH	VF	WHR
ST LOUIS	MO	LEMAY	P	MH	VF	WHR
GREENSBORO	NC	N BUFFALO		MH	VF	WHR
AMHERST	NY		W	MH	VFC	WHR
CINCINATTI	OH	LITTLE MIAMI	PW	MH	VF	WHR
CRANSTON	RI			MH		WHR
	MH WITH UNSPECIFIED METHOD OF WASTE HEAT RECOVERY = 10					

TABLE 5. INCINERATION FACILITY SLUDGE MASS DATA

CITY	STATE	PLANT		TYPE INCIN-ERATOR	OPERAT-ING STATUS	DRY SOLIDS LBS/HR	% DRY SOLIDS	ACTUAL WET MASS LBS/HR
PLANTS WITH FLUID BED INCINERATORS (TOTAL NUMBER = 9)								
REDWOOD CITY	CA			FBI	OP	4000	40.0%	10000
DUBUQUE	IA			FBI	OP	1600	30.0%	5333
KANSAS CITY	KS	KAW PT.		FBI	OP	2222	35.0%	6348
KANSAS CITY	KS	NO. 20		FBI	OP	400	25.5%	1568
OCEAN CITY	MD			FBI	OP	350	30.5%	1147
DULUTH	MN	WLSSD REGL		FBI	OP	6038	21.0%	28752
INDEPENDENCE	MO	ROCK CREEK		FBI	OP	2500	40.0%	6250
SOUTH DOWNS	NY	EIRIE CTY		FBI	OP	833	30.0%	2776
WATERTOWN	NY			FBI	OP	2500	40.0%	6250
PLANTS WITH FBI OPERATING = 9								
PLANTS WITH MULTIPLE HEARTH FURNACES (TOTAL NUMBER = 48)								
SAN MATEO	CA			MH	IOP	1200	42.0%	2857
BALTIMORE	MD	PATAPSCO WWTP		MH	IOP	35700	35.0%	102000
WASHINGTON	MD	WESTERN BRANCH	UPPER MARLBORO	MH	IOP	583	27.5%	2120
ERIE	PA	ERIE CITY		MH	IOP	2700	13.5%	20000
LEMOYNE	PA	BORO OF LEMOYNE		MH	IOP	400	20.0%	2000
NEWPORT	TN			MH	IOP	63	17.0%	370
PLANTS WITH MH OPERATING INTERMITTENTLY = 6								
PALO ALTO	CA	PALO ALTO REGL		MH	OP	1000	4.5%	22222
HARTFORD	CT			MH	OP	3750	21.2%	17688
SMYRNA	GA	R.L. SUTTON		MH	OP	1667	40.0%	4167
HONOLULU	HI	SAND IS		MH	OP	1995	28.5%	7000
CEDAR RAPIDS	IA			MH	OP	4000	45.0%	8888
DAVENPORT	IA			MH	OP	1875	50.0%	3750
SHAWNEE MSN	KS	TURKEY CRK #1	JOHNSON CTY WD	MH	OP	1500	20.0%	7500
ANNAPOLIS	MD	ANNE ARUNDEL CY		MH	OP	1200	35.0%	3428
BALTIMORE	MD	COX CREEK	ANNE ARUNDEL CY	MH	OP	4550	32.5%	14000
ANN ARBOR	MI	CY OF ANN ARBOR		MH	OP	3333	40.0%	8332
BAYCITY	MI			MH	OP	833	40.0%	2082
GRAND RAPIDS	MI			MH	OP	1500	45.0%	3333
KALAMAZOO	MI			MH	OP	2933	44.0%	6665
PONTIAC	MI	PONT SEW TRT DV		MH	OP	972	7.8%	12461
EAGAN	MN	SENECA		MH	OP	61	21.0%	290
MINNPLS-ST PAUL	MN	METROPOLITAN		MH	OP	4875	45.0%	10833
ST LOUIS	MO	LEMAY		MH	OP	4075	29.0%	14051
LEBANON	NH			MH	OP	656	22.0%	2981

TABLE 5. (CONCLUDED)

CITY	STATE	PLANT	TYPE INCIN-ERATOR	OPERAT-ING STATUS	DRY SOLIDS LBS/HR	% DRY SOLIDS	ACTUAL WET MASS LBS/HR
MANCHESTER	NH	MANCHESTER WWTF	MH	OP	1972	18.6%	10602
MERRIMACK	NH	MERRIMACK WWTP	MH	OP	1800	15.0%	12000
ATLANTIC CITY	NJ	ATLANTIC CY REG	MH	OP	2000	32.5%	6153
WAYNE	NJ	MT VIEW WPCP	MH	OP	6200	17.5%	35428
BUFFALO	NY	BIRDS IS	MH	OP	42000	16.5%	254545
DUNKIRK	NY	DUNKIRK STP	MH	OP	2083	12.0%	17358
NEW ROCHELLE	NY	WESTCHESTER CTY	MH	OP	1000	30.0%	3333
ORANGEBURG	NY	ORANGETOWN DPW	MH	OP	531	6.0%	8850
OSWEGO	NY	EAST SIDE	MH	OP	417	25.0%	1668
OSWEGO	NY	WEST SIDE	MH	OP	3000	16.5%	18181
SUFFOLK CO.	NY		MH	OP	300	40.0%	750
TONAWANDA	NY	2 MI CREEK 2	MH	OP	3200	40.0%	8000
CANTON	OH		MH	OP	1333	38.5%	3462
CINCINATTI	OH	LITTLE MIAMI	MH	OP	5500	50.0%	11000
CINCINNATI	OH	MILL CREEK WWTP	MH	OP	5083	43.5%	11685
CLEVELAND	OH	SOUTHERLY	MH	OP	22000	45.0%	48888
YOUNGSTOWN	OH		MH	OP	1875	30.0%	6250
TIGARD	OR	DURHAM REGL	MH	OP	356	22.5%	1582
JOHNSTOWN	PA		MH	OP	490	24.0%	2041
JOHNSTOWN	PA	JOHNSTOWN	MH	OP	2043	24.0%	8512
PITTSBURGH	PA	ALCOSAN	MH	OP	6700	25.0%	26800
YORK	PA	YORK WPC CTR	MH	OP	938	37.5%	2501
HOPEWELL	VA	HOPEWL REG AUTH	MH	OP	2000	25.5%	7843
LORTON	VA	LOWER POTOMAC	MH	OP	4813	17.5%	27502
NEWPORT NEWS	VA	BOAT HARBOR	MH	OP	2083	4.0%	52075
NORFOLK	VA	ARMY BASE	MH	OP	312	22.0%	1418
VA BEACH	VA	CHESAPEAKE-ELIZ HAMPTON RDS.	MH	OP	672	28.0%	2400
BROOKFIELD	WI	FOX RIVER	MH	OP	1300	40.0%	3250
GREEN BAY	WI	GREEN BAY MSD	MH	OP	3150	34.5%	9130
CLARKSBURG	WV		MH	OP	1081	22.0%	4913

PLANTS WITH MH OPERATING = 48

TABLE 6. TYPE OF SLUDGE DEWATERING AND CONDITIONING USED WITH OPERATING SLUDGE INCINERATORS

Information Furnished		Multiple-hearth Furnaces		Fluid Bed Furnaces	
Dewatering Equipment*	Sludge Conditioning	No. of units	% of total MHFs**	No. of units	% of total FBFs**
Centrifuges	Unidentified/None	3	1.5	0	0
	Polymer	30	15	8	33
	Chemical	0	0	0	0
	Thermal	10	5	2	8
Filter Presses	Unidentified/None	15	7	0	0
	Polymer	6	3	0	0
	Chemical	2	1	3	13
	Thermal	1	0.5	0	0
Vacuum Filters	Unidentified/None	104	51	8	33
	Polymer	13	6	3	13
	Chemical	5	2	0	0
	Thermal	30	15	2	8

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* The relatively small number of installations that reported more than one type of dewatering equipment have been counted once under each type of dewatering equipment.

** Totals do not include those installations that did not report dewatering method.

TABLE 7. TYPE OF WASTE HEAT RECOVERY SYSTEMS USED WITH OPERATING SLUDGE INCINERATORS

Type of Waste Heat Recovery	Multiple-hearth Furnaces		Fluid Bed Furnaces	
	No. of units	% of total MHFs*	No. of units	% of total FBFs*
Unspecified	10	4	3	10
Waste Heat Boiler	23	9	9	30
Hot Windbox	0	0	2	7

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* Totals include those operating installations where no waste heat recovery data were reported, with the assumption that none of those facilities have any type of waste heat recovery.

TABLE 8. SUMMARY OF FACILITY VISITS

FACILITY LOCATION	NAME	TYPE SLUDGE	SIZE (MGD)	TYPE INCIN	TYPE DEWATER	COND.	DRY SOLIDS PERCENT & VARIATION	SIZE	NO. OF UNITS	HOURS OF OPERATION	NO. OF OPERATORS	START UP DATE*	PERCENT CAPACITY USED	AUXILIARY FUEL TYPE	AFTER BURNER	WASTE HEAT RECOVERY
North Andover, MA	Greater Lawrence Sanitary District	CT P GT W	45	MH	BF, VF	PO	25 (+2,-3)	25'9" x 7	2	168	4	1977	80	Gas	No	No
Hartford, CT	Metropolitan District	P AFT W	60	MH	BF	PO	21 (-2)	22'3" x 11	3	120 240	7	1971	50	Gas Oil	No	No
New Rochelle, NY	New Rochelle	60% P 40% W	15	MH	VF	H	42.5	12' 10' x 6	2	168	4	1981	80	Gas	No	Yes
Buffalo, NY	Metropolitan District	20-24% P 60% P 20-40% W	150	MH	BF	PO	16 (+1,-2)	22'3" x 12	4	168	4	1979	80	Gas	Yes	Yes
Buffalo, NY	Erie County Southtowns	60% P 40% W	15	FBI	BP	CC	35 (± 5)	9'	2	168	2	1980		Oil	No	Yes
Green Bay, WI	Metropolitan District	GT P AFT W	52.5	MH	VP	H	35 (+5)	22'3" x 7	2	168	4	1976	80	Gas	No	Yes
St. Paul, MN	Metropolitan District	60% P 40% W	250	MH	RP	PO H	35 (± 6)	22'3" x 8	6	168	20	1966	80	Oil Gas	Yes	Yes
Atlanta, GA	R.M.Clayton	20-24% D 60% P 20-40% W	60	MH	C	PO	25 (± 5)	22'3" x 10	2	120	7	1974	80	Digester Gas	No	No
Smyrna, GA	R.L. Sutton	P W	20	MH	BP	C	40 (± 5)	12'10" x 8	1	120	7	1978	80	Gas	No	No
Norwalk, CT	City of Norwalk	60% P 40% W	15	FBI	BF	PO	25 (- 5)	12'	1	168	7	1974	60	Oil	No	Yes
New Orleans, LA	East Bank	CT W	122	MH FBI	C	-	20 (± 2)	18'3" x 9 12'	1 1	168 0	7 7	1967 1978	80 0	Gas Gas	No No	No Yes
Sommerville, NJ	Somerset-Raritan	P W		FBI	BF	PO	25 (± 3)		1					Oil	No	Yes
Annapolis, MD	Annapolis	P W	10	MH	C	PO	35 (± 3)	10'8" x 8	1	140	-	1975	60	Gas	No	No
Fairfax, VA	Lower Potomac	P W		MH	VF	CC	15 (+5)	22'3" x 7	4	168	16					

* Start up date reflects start of initial operations does not reflect new units or major modifications.

ABBREVIATIONS USED IN TABLE

MH	Multiple Hearth Furnace
FBI	Fluid Bed Furnace
BF	Belt Filter Press
VF	Vacuum Filter
BP	Plate and Frame Press
RP	Roll Press
C	Centifuge

PO	Polymer
CC	Chemical Conditioning
GT	Gravity Thickened
P	Primary Sludge
AFT	Air Flotation Thickened
W	Waste Activated Sludge
D	Digested Sludge
CT	Co-thickened

SECTION 5

PROBLEMS, POOR PRACTICES AND SOLUTIONS

In this section, identified problems and solutions associated with the operation of MHFs and FBFs are discussed. In general, these problems impact operations by increasing costs, reducing efficiency, and/or causing failures. The problems may be categorized as follows:

- System design deficiencies that relate to dewatering, equipment sizing, variable sludge feed composition and rate, and emission

- Incinerator equipment deficiencies and problems associated with furnace refractory, controls, fans, exhaust flues, conveyors, and other devices

- Operating problems that relate to slag and clinker; burners; screenings, grit, and scum disposal; and high calorific value sludge

- Administrative problems such as staffing, supervision, insufficient spare parts, lack of monitoring and control procedures, inadequate standards and/or low pay scale for operating and maintenance staff

- Training deficiencies related to lack of quality training for all levels of personnel.

Incinerator problems and poor practices cannot necessarily be neatly divided into these four categories. However, for our purpose, system design problems relate to the application and selection of methods and equipment for both the incinerator and support systems. These support systems generally consist of sludge dewatering, sludge feed, air pollution controls and ash handling. Problems that relate more specifically to the design and use of incinerator equipment components are discussed under equipment deficiencies. The proper selection and application of incinerator and support systems equipment are the largest issues facing the design engineer.

SYSTEM DESIGN DEFICIENCIES

System design deficiencies are problems identified during this investigation that are related to the selection of equipment for processing sludge using a conventional MHF or FBF during the design phase. The problems discussed were encountered at operating and nonoperating incinerator facilities.

Dewatering

Regardless of the type of incinerator, the extent to which feed sludge is dewatered has a major impact on incineration efficiency and costs. The low solids content of sludges dewatered by vacuum filters or centrifuges is a common problem at plants completed prior to 1979. In addition to reducing the equivalent dry solids throughput capacity of the furnaces, low solids/high moisture sludge requires larger amounts of auxiliary fuel to evaporate the water in the sludge prior to or during combustion.

In recent years, drier sludge cakes have been achieved at plants using filter press dewatering. Many older plants have replaced dewatering equipment with more efficient belt presses or recessed plate filter presses. In some cases, incinerator fuel consumption has been reduced by more than 50 percent as a result. Drier feed sludge also has eliminated the use of one or more incinerators, where more than one incinerator had been operated. Other savings have occurred in labor, power, and maintenance costs due to the higher solids and lower volume of sludge processed. In one case, the additional furnace capacity was used to accept sludge from outside sources, further reducing costs.

The payback period from supplementing or replacing dewatering equipment varied from three months to two years in the plants investigated. Excellent examples of the benefits of replacing dewatering equipment occurred at: Hartford, Connecticut; Frank E. Van Lare Plant, Rochester, New York; and Somerset Raritan Valley Sewerage Authority, Bridgewater Township, New Jersey.

Equipment Sizing

Oversized MHF and FBF incinerators exist at many plants as a result of selection criteria that are based on projected design loads which are never realized and/or sludge volumes in the initial years which are much lower than forecast. There are cases where installations must shutdown while sludge is accumulated in order to have enough feed volume to run one furnace for one or two days. Intermittent operation, particularly in a MHF, results in very high auxiliary fuel costs associated with cooling down and reheating to operating temperatures. Many facilities have abandoned operating MHFs because of high fuel usage related to intermittent operation or maintenance of the furnace in a hot standby condition.

Oversized furnaces also result from compounding safety factors during design. The following design factors strongly influence furnace selection:

- Peak week factors of 1.5 to 2.0 times average sludge solids per week
- Allowance for future growth over 20 or 30 years of 1.5 to 2.0 times present load
- Use of overly conservative criteria (i.e., design for the lowest likely solids content of the dewatered cake at the highest solids loading) with no turndown provisions
- The adoption of excessive safety factors on sludge cake loading in pounds per square foot of MHF hearth area or FBF fluidizing velocities and freeboard velocities to accommodate unrealized loadings.

Excess furnace capacity results in increasing capital and disposal costs for sludge. In addition, incinerator operation and maintenance costs rise for the following reasons:

- Labor costs may remain the same whether operating at full capacity or at part load. Operation of an incinerator less than 24 hours a day in order to run at full capacity during the operating period is not often feasible unless planned on this basis.
- Electric power costs for units operated at part load may be similar to operating at full capacity loading in order to run oversized motors at low-shaft output horsepower (furnace drive, turbo blowers). Alternatively, some motors may be run near design loadings with energy dissipation caused by pressure drop across a partially closed damper (induced draft fans). In either case, power is dissipated and higher costs are incurred.
- Fuel costs are higher due to frequent shutdowns, startups or standby heating for long periods. Extended sludge storage reduces dewaterability, increasing cake moisture and fuel required for evaporation.

- Cycling of the incinerator for intermittent use decreases refractory life. Because refractory brick life is proportional to the number of reheat cycles, refractory replacement is more frequent. Replacement of oversized hearths means more materials, more labor, and higher costs.

The impact of oversizing the FBF is not as severe as for the MHF. The most significant impact on the cost of sludge disposal is most likely to be the added capital cost attributable to a larger FBF unit than necessary. Labor costs for operation of a FBF unit or system larger than necessary will not be significantly affected as long as standby periods are short enough to prevent significant cooldown. Costs may be reduced if the available sludge can be procesed during one to two shifts per day. Similarly to the MHF, however, the FBF electric power costs will be higher per ton of sludge processed as required by oversized motors. Maintenance costs for the FBF will be severly impacted if long cooldown cycling of the refractory is allowed.

A common response to the problems and costs of using units with excess capacity is to shutdown operations altogether. When those responsible for providing and monitoring operating costs compare the cost for incineration on a dollar per ton basis with that previously paid for landfilling, haulage and land application, or other options, the cost of incineration with an oversized unit will not likely be competitive. Although future concerns for landfill exhaustion, land use, or imperilled water supplies may have been the impetus for implementation of incineration, the high cost of incineration often results in a return to landfilling or land application in order to decrease costs in the short term.

The decision to abandon incineration, especially in the first years of operation, is sometimes due to poorly trained operating personnel, malfunctioning equipment, difficult sludge characteristics, or uncorrected system or process deficiencies. The response to these shortcomings should be to provide training and a systems analysis to enable the plant to function as intended.

Treatment plant planning and design are generally based upon a 20-year period, with anticipated growth in plant loading. The problem of excess capacity in the initial years of operation is a given operational factor. Two design approaches may be considered to address this problem. One approach is to install furnaces that can be incrementally modified to use more hearths and/or combustion volume as sludge quantities increase. Such provisions or modifications need to be addressed in present day conventional MHF designs. An alternative approach is to use smaller multiple units to achieve incremental increases in furnace capacity. Although multiple units increase the capital cost of the plant, they provide considerable flexibility and increased reliability. If all the projected capacity is not initially provided, the benefits of changing technology and system improvements may be realized by delaying purchase of some units. The applicability of either approach is dependent upon the projected growth rate of the sludge load, as well as other considerations conforming to individual localities.

In existing MHFs, modifications are possible to minimize oversizing. Modifications have been made to the MHF to reduce the number of sludge processing hearths by cutting holes in the upper hearths to allow sludge to be fed two or three hearths lower. The burners on the upper hearths may be sealed off or used as afterburners if required. Reduced gas flows to scrubbers may be appropriately handled by variable venturi throats and/or variable speed fans.

Bypassing upper hearths by internal holes has also been useful when the feed sludge is considerably drier than anticipated, resulting in a feed that contains the planned solids loading, but less water. The same amount of combustion air would be required but less fuel and less drying. A 20 to 33 percent solids increase reduces wet cake weight to 60 percent of the original weight. Because sludge ignites at about 50 percent solids, the above change, even at the same of solids loading (kg/hr), would halve the required drying area and raise the volatile burning zone from, for example, hearth 4 to hearth 2. This change in sludge characteristics and the resulting combustion may not leave sufficient volume and time for mixing of air and volatiles for combustion prior to the exhaust port on hearth 1. Bypassing upper hearths would alleviate these conditions.

The "self-modifying" feature of the MHF also may be employed to handle low sludge feed rates or higher solids by allowing the sludge to burn on a higher hearth than normal, and permitting the lower hearths to simply transport ash. For low solids throughput on a prolonged basis, revising the operation to the higher hearths and discontinuing heating of the lower hearths could be practiced. The entry of excess air could be sealed off in the lower part of the furnace. Combustion air and gases would also be proportionately reduced. Such furnace modifications should only be undertaken after a careful study of the individual situation.

Variable Sludge Composition and Feed Rate

The effects and duration of variable sludge composition and feed rate may be very severe on day-to-day incinerator plant operations, O&M costs, and equipment replacement. Ideally, in-plant sludge storage before dewatering should be provided to minimize variations in daily quantities so that the dewatering and incinerator processes receive approximately constant volumes of sludge each day. Minimizing variation of feed rate and composition over short time periods (minute-to-minute and hour-to-hour) is very important in establishing steady and fuel-efficient incineration.

Constant temperatures and complete combustion depend on maintaining the correct air-to-combustibles ratio in the incinerator. If combustible quantities vary significantly, then near optimum combustion cannot be maintained.

The combustible solids content of the feed is the main regulator of combustion air. As an example, a constant loading of sludge cake in kilograms per minute at 30 percent solids contains 50 percent more combustible material than at 20 percent solids. If the combustible material increases from 60 to 70 percent at the same sludge feed rate, then the heating value of the feed is increased by 75 percent and the required combustion air also increases by 75 percent. If a 25 percent increase in feed rate also occurred simultaneously, the heating input of the feed would increase by 120 percent over the original condition and the required combustion air would be 120 percent greater. These changes are drastic compared to a relatively steady state process in wastewater treatment plants using blending tanks and multiple dewatering units. The above conditions describe radical changes in furnace heat input and extreme demands on the air and gas handling systems. Such variations may be well beyond the installed equipment capacity and excessive temperatures may result. In treatment plants, sludge feed variation resulting from the shutdown or startup of individual dewatering units is the cause of notable heat input changes that must be carefully handled.

In some plants, usual operations maintain sludge fairly consistent in solids, combustibles, and ash content. Generally, this situation occurs only where liquid sludge storage is fairly well mixed, and where primary and secondary sludges are kept at reasonably consistent ratios.

Most plants experience variations in solids and ash contents that are less extreme than the above example. Changes in "typical" sludge characteristics may last 5 minutes to 5 hours or more depending on the cause. Factors such as flocculant feed variations, intentional or unintentional variation in filter operating variables, grease in the liquid sludge feed, or feed of denser sludge near the bottom of the sludge storage tank are reasons for variability. Sometimes grit, screenings or scum are also fed intermittently to the furnace sludge feed for disposal. This practice greatly magnifies variations in sludge feed rate and composition. Because the incinerator is usually directly linked to the dewatering equipment with no intermediate surge bin, every change in the dewatering operation, flocculant feed variations, and grease in the liquid sludge immediately affect the furnace.

Depending on the cause of the variation, and the effectiveness of communications between the dewatering staff and the furnace operator(s), the operator may not be aware when feed rate or quality changes occur until temperature readouts indicate a markedly changed furnace condition. The operator has no way of knowing if the change will continue or return to the original condition. One operator may respond quickly taking over-corrective actions, while another may not respond in time or adequately to prevent smoke, slagging, or even equipment damage.

In the MHF, the effect of the change is more severe because there may be a radically changed condition in several hearths before the operator takes note. Unfortunately, the MHF responds slowly to control changes; and control changes to the MHF should be made slowly. Development of the ability to measure both temperature and excess air in the burning hearths could improve furnace control.

Another effect of variable feed sludge in the MHF is "double burning". When there is a marked increase in the solids content of the feed sludge, double burning may occur. For example, the solids content of a feed sludge could increase from 27 to 30 percent solids. This higher solids content sludge could suddenly ignite 10 to 20 minutes after entering the furnace. The preceding lower solids content sludge on the hearth below which is still burning at the normal rate would contribute more heat to produce double burning. This condition would increase the combustion rate in the affected zone with a very large increase in required combustion air. Once the higher hearth ignites, temperatures on that hearth and all hearths above may rise, causing a burning on yet a third hearth. Once double burning occurs, burning may continue on these higher hearths despite a return, a short time later, to the lower solids content feed sludge.

This characteristic of burning in the higher hearths of MHF's requires an examination of operation with dry sludge cakes at 35 to 40 percent solids or higher. Increasing feed solids from 27 to 30 percent decreases the quantity of water to be evaporated from 0.46 to 0.40 kg of water per kg of dry cake prior to ignition at 50 percent solids. This condition results in a 13 percent change in drying area requirement. Increasing feed cake dry solids from 37 to 40 percent decreases the water to be evaporated prior to ignition at 50 percent solids from 0.26 to 0.20 kg of water per kg of dry cake, a 23 percent change in drying area requirement.

Increasing the solids content of the feed sludge results in unstable combustion with a large increase in burning volatiles that require a large increase in combustion air for complete combustion without smoking. Failure to respond when the sludge feed content is 40 percent solids or greater can result in combustion on the top hearths of a MHF. Combustion space will not be adequate in such a situation and the lower hearths will be rendered useless. These occurrences are extremely serious and can result in flue damage, severe smoking, and excess temperatures, and limit furnace capacity to a level far below the design rating. Such conditions must be resolved by careful analysis because they are far beyond the normal utilization of a MHF.

The response of experienced operators to the problems of changing sludge feed characteristics is to try to run the MHF at maximum excess air at all times and to operate all burners while satisfying the "normal" condition heat balance. Then if problems occur, burners can be shutoff quickly. If initially operating at 150 percent excess air, smoking is less likely to occur when the combustion rate doubles.

The effects of variable sludge feed on the operation of FBF units is quite different from those in the MHF. Generally, the FBF requires a forced feed injection system to overcome the pressure in the furnace. The feed screw or progressive cavity pump is usually set at a speed or feed rate where feed surges are rejected and spill. Unusually dry sludge may cause "over pressure" stoppage of the feeder or plugging due to increased viscosity of the higher solids content sludge. As a result, the sludge feed to the FBF does not vary widely and, in fact, combustibles will be limited which increases the excess air requirement in the furnace. The adaptation of such feed systems to MHF's could improve MHF operation and reduce the chances for uncontrolled burning.

If minor increases in solids feed occur for the FBF, as in the example for the MHF (constant sludge rate, ash and combustible contents, changing only dry solids from 27 to 30 percent solids), a predictable change would occur. Operation of the FBF at 25 percent excess air would suddenly drop to about 15 percent excess air due to the 11 percent increase in combustibles. At the lower excess air level, the chance for smoking is greater depending on the bed and freeboard temperatures. In the FBF, the response time (a few minutes) for sensing increasing bed temperature is shorter than in a MHF, allowing a quicker response by the operator to reduce auxiliary fuel flow, restoring excess air to 25 percent. If autogenous sludge was burning, water sprays or reduction of the sludge feed rate would be necessary. Had the above change been in the opposite direction, from 30 to 27 percent solids, the FBF would operate at 37 percent excess air until sludge with higher solids was available or an adjustment was made.

Compounded increases in feed rate, heat value, and solids content are frequently encountered that result in unsteady conditions in MHFs and difficulty in regular operation at low excess air in FBFs. The inability to operate at planned excess air levels seriously affects fuel economy, capacity, and power consumption. Control upsets are not as noticeable or severe in FBFs as in MHFs.

In order to protect sludge incinerator furnaces in general against damage or slagging due to high temperatures from feed quality variation, operational controls must be set to limit the heat of combustion or temperature below a maximum point. Controlling operation to ensure that excess heat does not occur will cause the operator to reduce the capacity of the incinerator under average feed conditions. This practice will result in a loss of efficiency. Feed variations described above may require larger plants to run additional units or smaller plants to run more shifts.

A large portion of MHF maintenance costs can be attributed to variable sludge feed. The overall sludge handling system should be designed to minimize the rate and extent of feed variations to incinerators by provision of adequate sludge storage, mixing and proportioning of different sludges, preventing solids settling at the bottom of storage tanks, and decanting floating grease layers on sludge storage tanks. Dewatered sludge cake storage should also be evaluated and include back mixing provisions.

Furnace Emissions

Certain metals will sublime from the solid phase and recondense in altered chemical form in the gas phase. The particulate size for iron oxide, lead oxide or copper oxide formed when trace amounts of the chloride sublime and react in vapor phase to the oxide is extremely fine. Zinc reduced from salts to zinc metal sublimes from within a glowing particle, rich in fixed carbon, and then oxidizes in the gas phase to zinc oxide in a very fine particulate form.

Many of the difficulties experienced in meeting air pollution codes can be traced to these superfine particles.

Experimental results have shown typical dust to contain, in particles smaller than one micron, concentrations of metals which sublime as chlorides or as metals that are 1,000 to 10,000 times the concentration found in the main ash (7). The assumption sometimes made in determining emission levels that emitted particles will have the same composition as that of collected dust and ash is not correct.

Sulfur dioxide (SO_2) and sulfur trioxide (SO_3) emissions from sludge incinerators are usually far below emission levels allowed by code. The assumption that all the sulfur will become part of the combustion gases is false. Some of the sulfur in the feed sludge is incorporated into the ash. During emissions testing, SO_2 and SO_3 concentrations can become determining factors in whether the particulate limits are met. These compounds become absorbed by the alkaline ash as the ash collects on the filter apparatus in emissions testing, and are more completely absorbed in the water impingers behind the filter. Ammonia gas, which usually evolves from the initial drying of sludge on the first hearth of a MHF, also becomes absorbed in the water impingers, forming ammonium sulfate [$(NH_4)_2SO_4$] and ammonium sulfite [$(NH_4)_2SO_3$]. Certain state emission codes, as interpreted by state regulatory agencies, include the weight of the residue following evaporation of the water impinger, which will include the sulfuric acid (H_2SO_4) in the impinger, plus $(NH_4)_2SO_3$ and $(NH_4)_2SO_4$, and the weight of the filter catch.

Where grease is burned in a nozzle or burner separately from sludge, calcium salts behave similarly to other salts and are caught in the impingers.

These factors have, in at least one instance, resulted in the inability to obtain a certificate of compliance, plus extensive delay and costly litigation.

EQUIPMENT DEFICIENCIES AND PROBLEMS

Major component problems in both MHF and FBF systems were identified during site visits, telephone conversations with treatment plant personnel, and other sources. These problems are associated with MHF components including hearths, rabble arms, central shafts, induced draft fans, dampers, and thermocouples; FBF components, such as refractory domes, air distribution piping, and flues; and components common to both types of incinerators, such as ash handling, conveyors, waste heat boilers, air leakage, and scrubbers.

Failure of Hearths

MHF hearth failures can result from lack of feed rate control as well as frequent, rapid temperature cycling. However, hearths fail primarily due to sudden changes of temperature. Frequent cycling between 700 to 980°C (1,300 to 1,800°F) can be worse than controlled shutdowns. In normal operation where sludge feed is steady, properly constructed hearths should not fail in less than ten years, even with weekend or nightly standby cooling with properly controlled temperature changes under 30°C/hour (50°F/hour).

Proper record keeping can be helpful in predicting hearth failure. During internal inspections of the furnace, the high point on each hearth should be measured from a common benchmark such as the bottom of an inspection door and recorded. An increase in the rate of arch settlement indicates an impending problem. Refractory behavior is relatively unpredictable, however, and hearths that started out almost flat or even slightly negative in slope from perimeter to center have been known to last a year of more. If the hearths rise on initial heating, generally, they will have a normal service life.

Rabble Arms, Teeth, and Central Shaft

Rabble arms are subject to overheating and sludge dumping. A steady sludge feed prevents overheating the rabble arms. Adequate cooling air is vital to rabble arm life. The exit air temperature is maintained at 120 to 180°C (250 to 350°F) at the central shaft cooling air stack. Some manufacturers have not provided adequate pressure difference in the central shaft to supply sufficient cooling air to the rabble arms. Insulation can protect rabble arms; castable refractory covers appear to be effective even though the work to cover them is painstaking. Locating rabble arms so that sludge is dumped on the arms of the hearth below is a deficiency that can be corrected by designing the arms to rotate out of phase.

Rabble teeth may bend if exposed to short term high temperatures. The solution is to control temperatures by maintaining a steady sludge feed. Corrosion of the teeth is generally caused by chlorides. In addition, use of a two-part tooth avoids replacement of the tooth holder.

Central shaft problems include insulation, cracks, and patches. Various means have been used to reinforce the central shaft insulation; none have been entirely effective. The problem is the difference in coefficients of expansion for the cast iron shaft and the refractory.

Personnel at some plants are concerned about minor expansion cracks in the cast iron members. These cracks should not be a major concern. The cast iron can be allowed to "see" the fire as long as the area receiving the radiation is small and the surrounding cooling wall area is large.

Patches in central shaft insulation are difficult to maintain. The key is proper reinforcement which prevents the expansion of the reinforcement from cracking the patch and proper selection of patch material.

Induced Draft Fans

Major problems with induced draft (ID) fans can be primarily attributed to layout, and orientation of the fan and duct work; draft control; vibration; corrosion; sizing; noise; and drainage.

ID fans may have difficulty in meeting rated capacity and pressure due to fan inlet conditions. Sharp, short radius bends in the inlet duct and the resulting change in direction of the inlet gas stream upstream of the fan impeller can cause an unbalanced, nonuniform flow condition that reduces fan performance. Inadequate space for equipment layout is typically the cause. Modification of the inlet ductwork and the use of straightening vanes in ductwork with short radii can correct many flow problems.

Draft control and scrubber pressure drop are usually obtained by modulating the flow using an automatic damper. Some facilities have the damper located on the discharge of the fan; most facilities have the damper on the fan inlet. In almost all cases, an inlet damper to the fan is preferable to a discharge damper due to reduced power consumption by the fan. An inlet vane damper of the radial type or a parallel leaf damper mounted in an inlet box are good methods for providing volume and pressure control. Butterfly type dampers mounted in ductwork with the damper too close to the fan inlet can cause flow imbalance and a higher pressure loss than the inlet valve or parallel leaf dampers.

ID fan vibration is a problem that occurs too often prompting whe suspicion that the selection and support system of an inertia block foundation was not adequately considered. In many instances, the ID fan is located at a high elevation in a steel frame structure which requires a careful analysis to avoid harmful vibration. Impeller imbalance caused by the accumulation of particulates, tars, soot, grease and water, with subsequent loss of part of the build-up, is common in facilities. Vibration switches that permit quick fan shutdown are mandatory for a fan subject to accumulation of grease and solids to prevent damage due to excessive vibrations.

Even in a properly operated incinerator, a fan may become coated with sticky exhaust particulates that collect in the fan housing and impeller. A maintenance program should be established to keep the fan clean. Water sprays have been installed at some plants for continuous cleaning; however, the results have not been effective. Although sprays may reduce the rate of build-up of material, the materials do not readily wash away because of their composition. Mechanical cleaning usually gives the best results.

The combustible materials built-up in the ID fan can be ignited under certain circumstances. With a loss of scrubber water, the bypass dampers in a MHF system should open to protect the ID fan and scrubber from excessive temperatures. If the bypass does not open, the hot gases passing through the system can ignite fan deposits.

ID fan corrosion is a problem common to those facilities which have not selected the proper materials of construction. The design approach should weigh the selection of corrosion resistant metals consistent with resonable replacement costs of impellers, fan housing codings, and other design choices.

In many instances, improper sizing of the ID fan has severly limited furnace capacity and resulted in severe noise generation. The high pressure drop required for the scrubber may result on the selection of a fan with high tip speeds. However, if properly selected, the noise level can be maintained within acceptable limits. A characteristic fan tone noise in some instances has required the installation of stack silencers to eliminate the problem.

A common maintenance deficiency is the failure to keep the ID fan drains and stack drains clear. This equipment must be kept clear to allow the corrosive liquids to drain away. Drains of corrosion resistant material have been found to be necessary in many plants.

Serious problems with improperly selected ID fans may be correctable, but often at considerable cost. The long term effect of operation with a deficient fan can be extremely costly in terms of reduced sludge disposal capacity, limited furnace operation, or excessive power consumption.

Emergency Bypass Damper

In a MHF system, one of the most common problems is a poorly fitted bypass damper. Seating of the damper disc is normally imperfect in the large refractory-lined bypass stacks. As seat areas deteriorate and become worn, gases that have not been scrubbed can leak from the stack. Although an inflow of air to a lower pressure area below the disc should occur, untreated gases have been observed flowing from this area. Alternatively at high furnace draft, failure of the bypass stack damper to close reasonably tight can result in major in-leakage of air increasing the gas flow that the scrubber and ID fan must handle.

In addition, damper bearings installed on the bypass stack can overheat and seize, rendering the damper inoperable. The bearings should be offset from the stack with an intervening heat shield.

Thermocouples

Most ceramic shields for thermocouples in MHFs have been replaced with the Inconel 601 type. Thermocouples with 304 stainless shields are usually not suitable for service in combustion hearths.

Ceramic protective shields have had satisfactory service life in MHFs when special refractory shapes are provided above the shields to protect the thermocouple from dropping sludge. However, when the ceramic type shield is placed unprotected and in the path of dropping sludge, the thermocouple tends to shatter very easily. These conditions apply to ceramic type thermocouples in FBFs as well; however, the frequency of shatter is much less in FBFs because the thermocouple is suspended from the dome and less subject to physical impact.

Refractory Dome

In FBFs, failure of the refractory dome beneath the sand bed has been as severe a problem as hearth failure in MHFs. Just as some MHFs have had long hearth life while others have had frequent failures, the FBF refractory dome experiences are also varied. Maintaining constant temperatures or heating and cooling slowly are normally the key factors in avoiding problems.

In FBFs, an improved practice is to provide a recessed chamber for the single large burner, and introduce the fluidizing air heated by the burner flame to prevent localized hot and cold areas in the brick arch. This practice is probably more important when oil is used as the auxiliary fuel than with natural gas because of the luminosity of oil flames. In all cases, consideration should be given to uniform temperatures on brick domes or arches during heating.

When a windbox burner is used to preheat the FBF, shutting off the burner and letting the windbox grow cold after the operating temperature has been reached is a poor practice. If purchased fuel is used, continued supply of fuel below the bed support brick is preferred. Alternately, slow reduction of windbox temperatures (30°C or less per hour) is desirable where heat exchanger input will ultimately maintain a lower than startup windbox temperature.

FBF Air Distribution Pipes

Maintenance of FBF air distribution pipes can be difficult. Keeping the pipes locked in place in brick hearths and sufficiently tight to prevent sand from leaking into the windbox during shutdown periods is a problem. The cause is the fact that the metal pipes have a coefficient of expansion three times that of the brick hearth. Bed media (sand) leaking into the windbox is a nuisance, but not an irreparable problem. Like MHF rabble arm failures, the problem is not universal and is prevented by proper equipment design.

Exhaust Flue Corrosion

Chlorides and sulfur in the sludge cake are transformed during the combustion process to corrosive constituents that damage metal components in the furnace and flue gas system.

At incinerator temperatures, most chloride salts react with water vapor to produce hydrochloric acid (HCl) and the oxide of the cation. For example, calcium chloride ($CaCl_2$) plus water yields calcium oxide (CaO) and hydrochloric acid (HCl). Many metallic chlorides first vaporize, then react with water vapor in the gas phase, leaving an extremely fine metallic oxide dust plus hydrochloric acid vapor. Hydrochloric acid is corrosive in the dry state, as well as upon condensation. At metal temperatures above 430°C (800°F), alloys of the type used in MHF rabble arms and teeth are subject to dry corrosion by HCl. This corrosion is not generally a noticeable problem but can contribute to shortened rabble tooth life.

Where ferric chloride is used to coagulate sludge solids for improved dewatering, the ferric chloride will contribute chloride to the water leaving the dewatering step. The water retained in the dewatered sludge cake contains the same chloride (Cl-) concentration. For example, using 2.3 kilograms of ferric chloride per 45 kilograms of sludge solids for conditioning prior to dewatering will contribute 600 ppm of chloride to the water. Assuming all the chloride is in the retained water, dewatering the sludge to 25 percent solids would leave 0.2 kg Cl- per 100 kg cake dry solids. At 33 percent ash, the chloride in the ash would be 0.6 kg/100 kg ash. In addition, 0.02 percent HCl by volume will result in the exhaust gas if incineration occurs at near theoretical air, and 0.01 percent HCl by volume if incineration occurs at 100 percent excess air.

In addition to chloride from conditioning sludge for dewatering, another source for chloride can be wastewater that includes industrial effluents and salt water intrusion. These two latter sources can potentially raise the chloride content much higher.

Typically, the sulfur content of wastewater sludge is about 1 percent. Assuming that half the sulfur becomes sulphate salts in the ash and half goes to sulfur dioxide/sulfur trioxide (SO_2/SO_3) in the exhaust gas, then 0.04 percent SO_2/SO_3 would be contributed to the total wet exit gas volume at near theoretical air, or 0.02 percent in the total wet exit volume at 100 percent excess air. Sulfur dioxide/sulfur trioxide is generally corrosive only upon condensation with water or adsorption in water.

Furnace combustion gas will penetrate the refractory and insulation of the MHF as neither are gastight, allowing gas to contact the steel shell and flue. This gas, which has the same composition as the gas within the vessel or duct, will have effects similar to those described above. The most critical conditions occur when steel temperatures drop momentarily below the dew point of the gas causing water condensation which absorbs HCl and SO_2/SO_3 to create acidic solutions. When the temperature rises or the partial pressure of water diminishes within the flue duct or vessel shell, the water evaporates leaving concentrated acid on the steel. Repeated occurrences of these conditions will produce concentrations of hydrochloric, sulphuric, and sulphurous acids which attack the metal surface on which they concentrate. These conditions are considerably lessened in the areas where in-leakage of air occurs, diluting the concentration of corrosive gases near the steel surface.

FBFs normally operate under positive pressure and have a higher partial pressure of acids in the exhaust gases. FBFs have suffered from corrosion in exhaust ducts and at expansion joints. Although MHFs are not immune to the same phenomenon, the situation is mitigated by the normal infiltration air.

Proper handling of exhaust gas for either type of incinerator prevents corrosion problems. Transition from hot dry gas conditions to wet scrubber conditions must be accomplished without an interfacial zone subject to alternate wetting and drying conditions. The exhaust gas should be kept hot enough to keep all metal parts well above the temperature at which sulfuric acid condenses. The gas should pass into a wetted wall vessel where the flow of water covers metal parts and is sufficient to adsorb the acidic gases without significant change in water pH. These conditions will minimize corrosion.

Heat exchangers and waste heat boilers located ahead of the scrubber frequently have not been designed with consideration for local cold spots (e.g., first tubes contacted by the entering cold fluid) where metal temperatures are below the acid vapor dew points. A general rule for waste heat boilers would be to generate saturated steam above 2,070 kN/m^2 (300 psi) to maintain boiler metal temperatures safely above 200°C (400°F), and to raise steam generation pressures before acid bearing gases are allowed into the boiler, unless other special anti-corrosion measures are taken.

Dampers cannot make positive gastight closure. Therefore, if the boiler is to be bypassed, the boiler casing can be pressurized so that clean air is forced from the boiler through the dampers into the bypass duct.

The absorption of acid gases in scrubbers is not 100 percent complete, even in respect to very soluble HCl. The centrifugal collection of mist droplets carried through the scrubber produces some water. Chloride corrosion of ID fans following wet scrubbers was common until experience led to selection of special stainless steel alloys for fan parts. Depending on chloride concentrations, a variety of materials including 316L stainless steel, Inconel 600 series, and Hastelloy-C276 have been used. Similar corrosion can occur on exhaust stacks and other parts following ID fans. Drains, intended to remove condensate from ID fans, ducts and stacks have frequently been provided in corrodible materials and have required replacement with non-corrodible pipe.

The solutions to the problems raised by chlorides and sulfur in the sludge feed begin with recognition and consideration of the problem. Improved dewatering decreases sludge chloride content. Twenty percent solids sludge contains 4 kg of water per kg of solids, 33 percent solids sludge, 2 kg of water per kg of solids. The higher solids reduces the inorganic chloride content by half since all inorganic chlorides are water soluble. Use of polymer or ferric sulfate instead of ferric chloride in coagulation may be preferable.

External insulation of certain constructions is also necessary. Choice of proper materials for all parts in contact with incinerator off-gases is required, including heat exchangers, boilers, boiler casings, fans, stacks, and drain piping. In some cases, the correct solution is not an exotic material, but proper control of temperature of certain parts. In other cases, the avoidance or minimization of alternate wetting and drying is the proper solution.

Ash Handling

Of all the plants surveyed in a recent study (5) no plant was entirely satisfied with the ash handling system. Wet ash handling systems are more common for both MHFs and FBFs than dry ash systems. Problems have been experienced with both dry mechanical and hydraulic ash systems.

Dry Mechanical Type. The dust from non-tight dry systems creates a severe maintenance problem. The inability to keep the plant clean causes operator morale problems that further detract from performance. Common problems include the following:

- The ash drop hole and chute at the bottom of the MHF become plugged with large clinkers or loose brick. This problem can be reduced by adding a diversion chute and coarse screen. The fine ash will pass through the screen but larger objects will be diverted to the other chute for removal. This solution helps to protect ash conveying screws and bucket elevators.

- The ash bucket elevator chain frequently jumps off the sprockets. In some instances, these occurences were caused by poor alignment.

- Chains and sprockets of the wrong material have been selected. High hardness is needed to protect against the abrasive ash. The sprockets should be harder than the chain to prolong sprocket life.

- Bucket elevators should never be loaded greater than 80 percent of capacity and the loading should be considerably less. Most elevators have two chains, one on each side of the bucket. One chain is driven and the other is on idler sprockets and maintains bucket alignment. Some plants have removed the idler chain and sprocket, moving the ash with fewer wearing parts at the risk of incurring misalignment.

- Helical screws in covered troughs move ash horizontally or on an incline. Hard iron bearings support the screw and increase the bearing life against the abrasive ash. Hard iron bearings can be very noisy, generating a screeching sound. Many operators have added grease lubrication to the bearings. Lubrication has reduced the noise problem, but also has reduced bearing life as ash becomes entrained in the grease. At Green Bay, Wisconsin, use of wooden bearings solved the problem.

- The covers on screw conveyors are very difficult to keep dust tight. If all the gaskets, screws and clips on the cover are used, the dust is reduced. After maintenance, the covers should be put back with all the screws and clips in place.

- Ash conditioning screws and rotary drum ash conditioners have been only moderately successful in wetting the ash sufficiently to minimize landfill dust problems. Proper maintenance is mandatory for these items.

- Conditioning screws are frequently equipped with inadequate horsepower drives for moving the wetted ash.

- Control of the water for wetting has been difficult, requiring frequent operator attention.

- Ash conditioning is an area where additional research would be beneficial.

- At St. Paul, Minnesota, the ash conveyors have a vacuum dust removal system at the transfer points, which works well to minimize fugitive dust. Dust removal systems are rarely installed in incinerator plants.

Hydraulic Type Ash Handling. Problems with hydraulic ash systems are commonly associated with ash slurry handling. The abrasive slurry, consisting of bottom ash and fly ash, accelerates wear in all parts but especially in pipe elbows. High abrasive-resistant parts have long service life, but are expensive. Rubber lined pumps give excellent service.

Removing ash from ash lagoons is frequently done by private contractors. This operation is difficult because of abrasion and accelerated equipment wear. Although the ash slurry settles quickly in the lagoon, after removal, the slurry retains a large proportion of water for an extended time.

Ash from FBFs is very fine and is always captured as a slurry. This slurry has the consistancy of thick mud, even wetter than MHF slurries from lagoons.

Sludge Conveyors

Sludge cake conveyor systems are normally belts. Systems that deliver sludge to more than one incinerator may restrict operation of the incinerators at full capacity. Although a common practice is to divide the feed to the incinerators using plows, precise division cannot be obtained. The result is that incinerators may be unequally loaded. Devices on a belt conveyor that center the sludge prior to division with a plow have helped, but have not eliminated the problem. Cylinder operated plows on an automatic timer that remove 100 percent of the feed on the belt for one minute and pass 100 percent for another minute have been effective in dividing the sludge feed.

Plants that use sludge hoppers or bunkers for each incinerator have been most effective in maintaining a uniform feed rate to more than one incinerator.

Sludge cake conveyors located over the top of an incinerator have more maintenance problems because of the high temperature environment. Sludge cake that is not cleaned off the belt prior to shutdown becomes baked on and is difficult to remove. Elastomer and rubber conveyors have reduced life in the hot environment. Although plants with conveyors located to the side rather than over the top of incinerator have reduced maintenance, the side conveyors require a chute or screw conveyor to feed the sludge. Bridging of the sludge at the transfer point occurs if the angles are not steep enough to assure that sludge slides freely.

Some plants have added water sprays at transfer points to help keep the sticky sludge moving. Water sprays are not recommended because of the increased evaporative load to the furnace. Feed points should be redesigned to eliminate these problems.

Waste Heat Recovery Boilers

Dust loading design factors are critical in sizing a waste heat recovery boiler. The values in Table 9 are typically used by manufacturers in the waste heat recovery boiler industry. As dust loads increase, gas velocity must decrease to reduce erosion. Reduction of gas velocity increases boiler size and cost.

TABLE 9. TYPICAL DUST LOAD FACTORS

Percent Dust by Weight in Flue Gas	Maximum Gas Velocity, m/sec
10.2	10
0.32	15
0	20

Tube wall thickness should be increased for erosion protection where required. Other boiler design factors include the tube spacing for repairs, replacement, cleaning, soot blower lanes and dust hopper placement.

The location of control dampers can cause dead spots where dust can build-up when the dampers are modulated. Modulation changes the velocity distribution profile.

Heat recovery boilers for sludge incinerators may require a relatively large amount of steam for soot blowing. Availability of the steam may be a problem. Air systems are sometimes used in lieu of steam.

An auxiliary heating system may be required to protect the boiler against condensation and corrosion during long standby periods.

Equipment Related Air Leakage

Air leakage into the furnace related to system components may prevent furnace operation at design conditions and may reduce efficiency. In a recently constructed plant, misalignment of a precooler to a venturi scrubber did not permit closing of the water seal. The air introduced into the off-gas system at this point reduced furnace capacity until the misalignment was corrected.

At another plant with two furnaces and one waste heat boiler with interconnecting duct work, dampers on the offline furnace did not seal properly. Air in-leakage was sufficient to reduce furnace capacity. A check of similar misaligned equipment is well worth the effort in new or older plants.

Air Pollution Control/Scrubbers

Approximately 9 kg of uncontrolled particulates per metric ton of sludge (20 lbs/ton) are generated in MHFs and 0.0005 kg of particulates per liter (0.0038 lb/gal) of fuel oil fired (8).

The Federal New Source Performance Standard of 0.6 kg of particulates per dry metric ton (1.3 lb/ton) of sludge can be met with modern high energy wet scrubbers, such as the venturi.

Removal efficiency is a direct function of particle size and the amount of energy (or pressure drop) designed into the scrubber system. Typical published values (8) for percent removals of different particle sizes are in Table 10. Size distribution data from literature (8) for sludge incineration are presented in Table 11.

TABLE 10. REMOVAL EFFICIENCY OF PARTICLES

Particulate Size Range, microns	Removal Efficiency, percent
< 0.5	75
0.5-1.0	96
1.0-5.0	99.9
> 5.0	100

TABLE 11. SIZE DISTRIBUTION OF EXHAUST PARTICULATES

Size Range microns	Percent
< 0.5	1.6
0.5 - 1.0	2.2
1.0	8.2
> 5.0	88.0

Problems in meeting air pollution requirements have resulted from excessive submicron particles with a high percentage of unburned organics, primarily hydrocarbons. Improved combustion control of the incinerator usually corrects the problem of unburned organics.

Variation in scrubber water flow may also cause problems. This variation may result from a strainer in the scrubber water supply that tends to plug frequently or from a supply system with multiple demands that has inadequate flow and pressure control.

The problem of abrasion of the venturi throat has been corrected by using more wear resistant material such as silicon carbide. Corrosion of the impingement tray separator section may occur at the liquid gas interface above the tray sections. A change of material or use of thicker material has corrected this problem.

The control actuator on variable throat venturis may tend to stick and cause erratic operation. This problem may be an undersized actuator or an inadequate control system.

Excessive water carryover from the exhaust stack can be caused by an inadequately designed demister section in the scrubber, which is corrected by proper baffling and drains within the scrubber.

In one case, an improperly designed scrubber permitted excessive water carryover from the stack creating a local nuisance. Proper demisting and drainage within the scrubber system would have reduced the water carryover.

OPERATING PROBLEMS

Improved operation of an incineration system is dependent upon the ability to deal with common operating problems of slag and clinkers; burners; screenings, grit, and scum disposal; and high calorific value sludge.

Slag and Clinkers

Clinkers are free lumps that occur in the burning bed of MHFs that are carried to the cooling hearths. Slag, which can occur in a MHF or FBF, is the accumulation of fused material on the walls and dropholes, rabble arms, etc. Failure to recognize the ash melting temperature under both oxidizing and reducing conditions and to make proper tests has resulted in severe operational problems and increased maintenance costs due to slag and clinker formation.

Although not a common cause, certain polymers may contribute to clinker formation unless the sludge cake is well shredded to below 1.3 cm (0.5 inch). However, shredding has not been adopted in many plants. Shredding may also be necessary where sludge cake pieces are well compacted by filter press dewatering equipment.

The key cause of slag and clinkers is high temperature, which is usually caused by erratic feed. The erratic feed causes the temperatures to go beyond the desired maximum temperature. The temperature of the hot bed is considerably higher than the temperature indicated by the thermocouple. Based upon observations, one MHF manufacturer concludes that the highest temperatures occur in the upper portion of the combustion hearth where the sludge volatiles mix with air when they are passing through drop holes. The greatest slagging potential is observed to occur at the drop holes, particularly in the outer drop hole area. The intense heat from combustion heats the refractory at the drop hole and when fine ash particles contact the refractory, they adhere and build-up. Eventually, the drop holes can plug entirely. Lanceports should be located in these areas.

The problems of slagging and clinkers deserve more extensive treatment than can be addressed in this report. Operators with these problems should seek expert advice to:

- Analyze where air enters the furnace, quantify, and adjust burner excess air as necessary
- Readjust rabble teeth to break up lumps and to retain lumps longer in the fixed carbon hearths
- Change chemical conditioning if necessary
- Shred very dry sludge cake
- Employ a clinker resistant ash system.

Slagging occurs in several forms. Oil and dust can create slag on burner tiles. Grease burned on a hearth may create local hot spots or a local area of ash melting, causing slag. Sludge left on rabble arms can be carried through the burner flame zone and held at the junction with the central shaft producing a roaring volatile flame which turns the sludge to slag. Lastly, dust carried in the gases from the lower hearths can pass through burner or volatile flames, become molten while in suspension, and then stick to the first contacted surface. If the surface is cool enough, the molten droplets freeze and drop away. If the surface is sufficiently hot, alternating strata of cinder and glass deposit on the surface. If the surface collecting the molten droplets is hot enough, the deposit is glass-like and penetrates the refractory until the deposit can only be removed by breaking away the brick surface. The slag is taffy-like while hot, and if heated another 55 to 220°C (100 to 400°F), the slag will become fluid and slowly dissolve the brick.

The slagging problem is usually better understood and correctable where the analysis is not based only on oxygen measurement in the top hearth. Excess air at this point is affected by air leakage into the furnace above the burning hearth. Conditions in the combustion hearths should be explored.

In general, if the combustion zone temperatures are below 900°C (1,650°F), slag and clinkers are not a problem; however, bed temperatures and hot spots frequently exceed this value in localized areas. Most research on ash has been performed on coal and solid waste. Additional research is needed on wastewater sludge ash in order to estimate its clinker and slag potential. To illustrate percentages of components found in a range of coal ash, Table 12 is provided. These elements exist in these ranges in at least three sludge burning facilities.

When fluxes such as lime, magnesia and iron compounds are present in ash, the ash melting point is lower by an amount dependent on the total quantity of fluxes and on their relative

TABLE 12. ESTIMATES OF ASH COMPOSITION

Component	Typical Range, %
Silicon Dioxide (SiO_2)	20-60
Aluminum Oxide (Al_2O_3)	10-35
Ferric Oxide (Fe_2O_3)	5-35
Calcium Oxide (CaO)	1-20
Magnesium Oxide (MgO)	0.3-4
Sodium Oxide (Na_2O)	1-4

proportion. Because ash is a mixture of various components, the ash does not usually have a definitive melting point. The gradual softening and fusion of ash is not merely the successive melting of the various constituents, but is a more complicated process in which reactions involving the formation of new compounds take place. Accurate correlation of the chemical composition of the ash with the fusion point is virtually impossible.

Determination of "ash-fusion temperatures" is strictly a laboratory test procedure developed in standardized form. The test can be duplicated with a high degree of accuracy. The initial deformation temperature defined by the test corresponds to the temperature in an operating furnace at which particles of ash, in transit through the furnace, have a slight tendency to stick together or slowly build-up on heat-absorption surfaces. The softening temperatures (sometimes called the fusion temperature of an ash), also defined by the test, correspond to an observed condition between initial deformation and fluidity. To the operator, this temperature is related to a greatly accelerated tendency for the ash to mass together and stick in large quantities to heat-absorbing surfaces.

Solutions to slagging and clinkers involve manipulation of air flow and oxygen supply. In the MHF, one solution may be to reduce the fixed carbon burning rate by decreasing the oxygen concentration over the bed. This solution will reduce overheating on the combustion hearth above. Another solution may be to increase the air flow into the volatile burning hearth after reducing the air on the fixed carbon burning hearth. Slagging problems encountered with thermally conditioned sludges have been corrected by resizing burners for 100 percent excess air. Slagging caused by ash melting when passing through the burner flame has been eliminated by reducing flame temperature. Lower flame temperatures are obtained by higher burner excess air. Most burner instruction books are directed toward use in boilers where the higher flame temperatures are desirable.

Other methods to alleviate slagging problems are:

- Providing lance holes at outdrop holes
- Enlarging drop holes in the combustion zone
- Increasing turbulent mixing of gases to provide a uniform fire from one side of the furnace to the other
- Adding air below the fire, not above the volatile burning hearths.

Burners

Carbon build-up around burner tiles is an indication of an improperly adjusted burner. Other problems caused by maladjusted burners are slag, clinkers, refractory damage, and furnace shall damage from burnback. Typical reasons for lack of proper adjustment are failing to use the proper orifice plates in making adjustments and setting up the excess air so low that high flame temperatures cause the ash to slag. Boiler burners are adjusted for theoretical flame temperatures above 1,650°C (3,000°F).

Screenings, Grit and Scum Disposal

Screenings, grit, and scum demand special handling when processed in an incinerator. The impacts on the incinerator, particularly the MHF, have been adverse. Relatively few such furnaces have performed satisfactorily. The experience of plants utilizing MHFs adapted to burn screenings, grit, and scum are discussed primarily to illustrate the difficulties. The adapted furnaces have been largely inadequate for this service and there is considerable risk to the furnaces and to emission violations caused by incomplete combustion.

MHF Experience. Collected screenings clog feed mechanisms and have a high moisture content. However, screenings are more easily handled when shredded. At one plant, screenings are transported pneumatically to a ram feeder and introduced into a MHF specifically designed for burning only screenings. This furnace is expensive to operate and requires constant attention to maintain feeding equipment.

Grit has, in many instances, been fed onto the conveyor belt carrying sludge to MHFs. Grit is extremely abrasive, can contain large quantities of organic materials, and at times can be relatively dry. When burning grit, a deficiency of combustion air and the generation of black smoke has been observed in many MHFs.

Grease or scum has been blended with sludge in sludge thickeners, dewatered, and the resulting sludge cake fed to hearth No. 1 in MHFs. Burning the blended sludge has caused uncontrolled burning and unburned carbon in the flue gases. This practice has been discontinued.

Many other MHFs have been equipped with pipe manifolds and pipe nozzles to feed grease into the combustion hearth at two or three points. With pipe nipples sufficiently large to prevent plugging, excessive grease flow results in severe local burning of grease at these feed points on the hearth. Slagging in the hearth and the generation of unburned carbon due to the lack of required combustion air at the grease feed points has also been experienced.

Many MHFs have experienced the above problems, whether grease was blended with sludge in thickeners or by other means, or if grease was pumped to a pipe manifold and feed points at the combustion hearth. The key issue is that the high heating value of the grease and scum (up to 38,800 kJ/kg) requires combustion air commensurate with the heat release. Combustion air to supply such local heat release is not available in the normal air distribution system of a MHF. The furnace, as designed with the zoning divisions and limited combustion area, is not well suited to scum and grease drying and combustion.

Scum or Grease Burning Alternatives. The FBF is more adaptable to burning grease, oils and other materials of high calorific value. Pumping and extruding fuels directly into the media bed are the normal feeding methods in the FBF. Within the last ten years, ten FBFs have been designed and put into service to burn both sludge and grease. FBFs designed solely for grease have been operating at Cleveland, Ohio (Easterly Plant); Charlottesville, Virginia; Decatur, Alabama; and Philadelphia, Pennsylvania (Northeast Plant). These FBFs are designed to similar engineering criteria as sludge burning FBFs and have a freeboard internal diameter ranging from 2 to 4.5 m (7 to 15 ft) to illustrate the range of sizes.

Scum burning refractory units designed with steam or air atomizing burners in a separate chamber have had a very minor place in municipal wastewater treatment plants. These burner units require fuel preparation for satisfactory operation such as grinders, pumps, storage and decant tanks, heaters, oil storage tanks, oil heaters, steam supply and combustion safeguard equipment. The relatively few reports on such units indicate that they are physically small and require a high degree of attention for successful operation.

High Calorific Sludge

An interesting example of operational problems where high calorific sludge was fed to a MHF occurred at a wastewater treatment plant in the Midwest. The sludge contained cutting oils from local industry and was composed of premixed floatables and sludge from a storage tank. Compounding this situation, the sludge feed rate was extremely erratic. Filter press output rates and sludge cake weights varied up to three times during an 8-hour shift. In addition, sludge solids content ranged from 35 to 50 percent. Dewatered sludge cake was discharged directly to conveyors that delivered the sludge into an unconstricted furnace inlet port. No alternate discharge points were provided.

The resulting combustion produced such variations of temperature that the hearths expanded, raising the rabble teeth (about once per shift) which created an upward pressure on the central shaft. The furnace hearths withstood the intense heat and expansion and temperature cycling from 650 to 1,040°C (1,200 to 1,900°F) for two to three years. The unit would belch clouds of black smoke each time ignition occurred on hearth no. 1, due to the lack of combustion volume between the ignition point and the scrubber entry flue.

Operational problems were solved by bypassing the upper hearths and by converting two hearths from drying to combustion hearths to obtain satisfactory combustion due to the high volatile content of the sludge.

In retrospect, this high oil and grease sludge could have been better handled in the MHF using fuel efficient operation (starved air combustion) and an afterburner. An afterburner chamber may have been designed to use the high exit temperature produced by the high volatiles and solids feed.

Alternately, a FBF would have provided the proper combustion volume for the oils and grease. The quick response of the FBF to operational changes would have made control feasible and easier.

ADMINISTRATIVE AND ECONOMIC PROBLEMS

The following administrative problems were found to be common to both MHF and FBF processes:

- Lack of system knowledge by senior management
- Inadequate staffing and supervision
- Inadequate supply of spare parts and supplies

- Poor documentation and review of process data
- Low pay scale resulting in low standards for operating and maintenance staff
- Lack of operator training.

The administration of a wastewater treatment plant, and especially an incineration process, requires a carefully thought out, detailed, multifaceted plan. The goal of this plan should be to operate the process in the most cost-effective manner possible, while meeting the overall objectives. In order to meet this goal, an administrator must consider all the elements that impact the process or that will be impacted by the operation of the process.

To properly administer the operation of an incinerator process, senior management personnel must have a working knowledge of the system. This knowledge includes the expected results of the system and a method to evaluate system performance including O&M costs and operator training. In addition, management should have a system to evaluate personnel performance and establish personnel accountability.

In the incineration process, an adequate staff must be present to routinely monitor and optimize the process. In most plants, the dewatering and incineration processes are operated by different operators. These operators must communicate so that the dewatering operator can relay changes in sludge feed (volume, solids content, volatility and duration of dewatering operation) to the incinerator operator in time for him/her to adjust the incinerator to the anticipated change in the system's primary fuel, i.e., sludge. Too often the adjustment to the incinerator is reactionary rather than planned, and poor system performance and excessive O&M costs result.

To properly operate an incinerator, the operator must not only monitor the data readouts of control room instruments, but also make frequent observations of the process at the incinerator. Many problems can be avoided by visual and audio observations at the process. For example, an operator who routinely checks the color and location of the burning sludge and correlates these data with changes in oxygen levels and movement of the burn zone (in MHFs) becomes much more aware of combustion conditions than by simply observing a strip chart recorder in the control room.

Inadequate supervision was the most common staffing problem in the facilities visited during this investigation. Unless someone is keeping a close watch on process cost and performance efficiencies, there is little chance the process will meet the design intent and that operators will receive the input necessary to improve their performance.

Few facilities visited during this investigation had an adequate supply of spare parts and supplies to support O&M needs. Generally, this problem can be attributed to either funding limitations and/or poor budget planning. O&M personnel who lack the necessary spare parts and supplies to maintain the incinerator will experience increases in downtime and costs for solids handling.

Poor documentation and review of process data are typical administrative problems with incineration facilities. Most facilities require O&M personnel to take hourly readings of process data. In many cases, these data are not utilized for actual process control or optimization of the system but only to ensure that the operator has made hourly rounds to check on equipment.

The concept of process optimization was included as a startup requirement on most federally funded incinerator installations. However, whether through a general misunderstanding of what process optimization really is or through lack of concern, experience seems to indicate that attempts to optimize the process stop after the system startup requirement is signed off.

Optimization is an ongoing process that can also be referred to as process trend analysis. Administrators should insure that incinerator process data are recorded and trend plots developed that graphically illustrate when key process variables are trending out of an established window of optimal operating efficiency.

Personnel responsible for incinerator operation must have a working knowledge of some engineering theory, a mechanical aptitude and the ability to troubleshoot process/equipment problems. During this investigation, observations indicated that many incinerator O&M personnel appear to have little to no understanding of the process theory, interrelationship between subsystems, mechanical functions/requirements of the various process components, or knowledge of the basic thermodynamics of the process. In other installations, highly skilled O&M personnel were optimizing process performance and efficiencies to minimize O&M costs. Ensuring that the O&M staff is well trained, motivated and maintains a professional attitude is far more cost-effective than to turn over O&M responsibility to personnel who are not adequately equipped or motivated.

Noncommensurate pay scales for personnel who are adequately skilled and qualified to meet the O&M needs of incinerator operation is an administrative problem that results in frequent personnel turnover and lack of continuity in system operational modes. Further, a single operational mistake that results in damage to an incinerator or components could cost in excess of any savings realized by employing low paid personnel.

TRAINING

This investigation has indicated that one of the most severe problems in incinerator operation is the lack of quality training for operations, maintenance and supervisory personnel. Most personnel in facilities visited during this investigation received training as part of the process startup requirements. Far too many of these personnel have not received any additional training after this initial effort.

Training during the startup phase is necessary and important, but is not sufficient to ensure that long term training needs are met. The startup of complex systems, such as incinerators, is subject to a large number of influencing factors that tend to have a detrimental impact on training provided during this time. Startup factors interfering with personnel training include: debugging of system controls, scheduling problems with other plant processes to deliver the required amount of feed sludge, resolution of contractor punch list items, warranty concerns, and availability of wastewater treatment plant management personnel to participate in training sessions.

For incineration systems, the supplier must assist in the initial training of personnel and help the plant staff place the system in operation. However, plant administrators must realize that this training will be influenced by the above factors and by the need of the supplier to gain acceptance of the system.

In several plants visited, the supervisory personnel responsible for the overall management of the plant had a lack of understanding of incinerator operational capabilities. This condition is a problem because management personnel in these plants cannot monitor the efficiency of the operation and performance of their personnel. This understanding is critical because the cost of incinerator operation can escalate to two or three times the optimum cost without efficient operation of the process by knowledgeable operators.

SECTION 6

COMPARISON OF MULTIPLE-HEARTH AND FLUID BED INCINERATION SYSTEMS ADVANTAGES AND DISADVANTGES

In this section, the advantages and disadvantages of conventional MHFs and FBFs are discussed. The discussion is based upon units as they are currently used for municipal sludge combustion. Practical plant size, flexibility and a comparison of several design and operational issues are discussed, followed by discussion of emissions, fuel requirements, maintenance, electric power, labor costs, and inorganic chemical conditioning.

These discussions are necessarily subjective as they are based upon current practices and understanding of the processes used in the United States at municipal wastewater treatment plants. Neither the MHF nor the FBF system has been applied to the best advantage in municipal sludge disposal. However, both incinerators have been successfully applied in a wide variety of industries where specific advantages of each are recognized. Each furnace can process many different combustible materials containing low solids levels. The ability and the need of each furnace to operate at low excess air levels has been proven in many industrial applications.

A comparison of the advantages and disadvantages between MHFs and FBFs, based only on conventional usage, is marginally useful in addressing current changes and future applications of these incinerators in both new and existing plants. Consideration of developing modifications to present equipment and operating modes, some of which can be applied to existing units, will reduce the disadvantages and change the relative comparisons between the incinerators. Currently, new techniques and systems are available which modify the conventional furnace process using fuel efficient combustion (starved air combustion), heat exchange, and new methods for introducing auxiliary fuels.

As the need for competitive sludge disposal methods increases, technological improvements in both types of furnaces will very likely occur, increasing their ability and efficiency to address the present problems associated with sludge combustion. At the same time, designers of wastewater treatment plants will also increase their understanding of the importance of controlling sludge feed variations, furnace sizing, and system integration.

The basis for determining advantages and disadvantages of the two types of furnaces is affected to a very large degree by the need to meet present and developing design and regulatory criteria for odor control, hydrocarbon destruction, furnace exhaust temperatures, and other parameters. The ability of a sludge incineration system to conform to such criteria has influenced furnace selection in the past and will continue to do so in the future.

PRACTICAL PLANT SIZE

Practical plant size for incineration of sludge is primarily dictated by the availability of other low cost disposal methods such as landfilling, land application or composting. Generally, smaller wastewater treatment plants have options such as these that are viable and less costly for small volumes of sludge. Other factors influencing sludge disposal selection include the location of the plant and land availability for alternative, more economical disposal methods. Smaller plants in the Eastern States may find incineration the best method, where plants of equal size in less industrial, more rural areas may not. Sludge characteristics also affect the decision to incinerate.

In general, incineration is more cost-effective in larger installations where support facilities are readily available and alternative disposal options are limited. An approximate plant size at which incineration becomes feasible might be about 75,700 m^3/d (20 mgd) for a MHF system and 37,900 m^3/d (10 mgd) for a FBF system. Other factors that dictate practical plant size include the following:

- The opportunity to incorporate energy saving features into the overall treatment process by waste heat recovery, steam generation, use of the incinerator for odor control treatment from other processes, and digester gas use for auxiliary fuel makes incineration more cost-effective.
- O&M personnel with comparatively sophisticated training are required to operate and maintain incineration plants. Maintenance and instrumentation personnel with the necessary skills are not normally present at smaller plants.

- Incinerators require considerable spare part inventories and preventive maintenance programs to minimize downtime, which may not be feasible in the small plants.

Based upon unit sizing in the past, the FBF is available in smaller sized units than the MHF. Another advantage of the FBF for smaller plants is the flexibility to shutdown for short periods of time without using significant amounts of auxiliary fuel, allowing operation at one shift per day.

OPERATIONAL FLEXIBILITY

In typical municipal wastewater treatment plants, sludge quantity and quality are based upon planning data for conditions over a 20-year design period. These data have limited usefulness because the sludge quantities may not be realized and the sludge quality is generally not based on actual sampling and testing. Incinerators designed upon these data may have operational problems because the design sludge characteristics may not match or come close to actual sludge quantity and quality. Where incinerators have been added to an existing treatment plant, and sludge characteristics sampled, tested, and defined, application and operation of incineration have been more successful. Where projected conditions are the only basis to size and select incineration equipment, more attention should be given to system flexibility, phased construction, and use of multiple units.

Based on current use in municipal plants and available manufacturers' products, the FBF provides more flexibility in furnace operation than the MHF. The primary advantage of the FBF is the ability to operate less than 24 hours per day. The FBF is also more responsive to variations in feed quality and rate than the MHF. However, the FBF is limited by fluidizing air requirements, which means the unit should operate near design loading even for short periods. In addition, the FBF is more capable of handling scum, grit and screenings than the MHF.

DESIGN AND OPERATIONAL COMPARISONS

Comparison of design and operation of the MHF and FBF is primarily in the areas of sludge feed; bed media; ash, and grease and scum handling; slag and clinkers; construction; and instrumentation.

- The FBF can accommodate shorter periods of sludge feed by operating fewer hours a day and can be placed on standby for the night without experiencing an appreciable loss of heat in the bed. The MHF cannot be operated intermittently and for short periods without maintaining furnace temperatures at the expense of auxiliary fuel.

- The MHF does not require a regular supply of bed media (sand) and is not likely to incur as much erosion damage in the flue gas system as is the FBF due to normal infiltration air.
- Where a MHF uses a dry ash handling system, the lower weight dry ash is cheaper to haul and landfill than the wet ash from a FBF system.
- FBFs can better accommodate grease and scum which can be used as auxiliary fuel in sludge burning. These materials can burn in the well mixed bed which supplies good contact with combustion air.
- Slagging and clinkering may be more easily handled in a MHF because of the accessibility provided by furnace doors. Although this advantage is marginal, slagging in a FBF may cause defluidization or shutdowns for long periods to remove the slag.
- The FBF system requires gastight construction. MHFs are under negative pressure and must be designed to minimize air infiltration to maintain thermal efficiency but are not necessarily gastight. Both systems must have well designed furnace refractory settings and flues.
- Instrumentation and control systems, as presently applied to the two furnace systems, provide easier control of the FBF which has an inherently simpler thermal process. Better use of the MHF, resulting from low excess air operation, a longer drying period, and other factors will enable the MHF to attain greater use of similar control techniques in the future.

EMISSIONS

With some local exceptions, both types of furnaces can meet present federal emission standards. In many cases, emission levels may be decreased through improved combustion control. In the future, increasingly stringent emissions requirements may influence furnace selection.

Under normal operation FBFs have exhaust temperatures at about 760 to 810°C (1,400 to 1,500°F). This operational feature of the FBF provides afterburning capabilities that destroy odors and hydrocarbons, and reduce particulates.

In some locations, air emission standards and sludge characteristics require MHF's to incorporate afterburning to destroy odors and burnout hydrocarbons. Present afterburning methods use considerable amounts of auxiliary fuel, raising operating costs. Given the present use of the MHF, the FBF has an advantage where afterburning is necessary. In the event afterburning is required at exhaust temperatures of 870°C (1,600°F), the FBF can be and is operated at this level.

FUEL REQUIREMENTS

A comparison of fuel requirements between the MHF and FBF must be based on the characteristics and type of sludge feed to the furnaces. These characteristics include volatile content and odor potential.

FBFs perform better where high volatile content sludges are incinerated. The typical 50/50 mix of polymer conditioned raw primary/waste activated sludge is in this category. For example, with a 75 percent volatile sludge, a hot windbox FBF can be operated autogenously at design excess air with 22 to 24 percent solids in the sludge feed. With a 60 percent volatile sludge, autogenous conditions in a hot windbox FBF can be attained with a 27 to 30 percent solids sludge and 35 to 50 percent excess air. In contrast, autogenous conditions in the MHF can be attained with a 60 percent volatile content sludge at 25 percent solids, and 40 percent or less excess air.

The FBF has better fuel efficiency than the MHF if afterburning is required. Afterburning is either becoming mandatory or being achieved through regulatory influence in an increasing number of states for odor control or to resolve other issues such as hydrocarbon reduction. In the FBF, all exhaust gases pass through a 760 to 810°C (1,400 to 1,500°F) zone before exiting from the furnace. Odor causing components of the exhaust gas usually have ignition temperatures under 770°C (1,420°F) and are destroyed.

In the MHF, furnace exhaust gas temperatures range from 320 to 480°C (600 to 900°F), maintaining correct operating temperatures in the combustion zone without afterburning. For sludge with odor causing exhaust gas constituents, afterburning may be required in the MHF. However, MHFs may operate with reduced fuel requirements with less odorous sludges, such as lime and ferric conditioned primary and trickling filter sludges. With these types of sludges, odor causing constituents are minimal and afterburning would not normally be required.

Conventional auxiliary fuels for both furnaces are oil and gas. In some cases, digester gas is used to replace or supplement these fuels. The FBF can operate on nonconventional types of fuel as well, such as coal or refuse derived fuel. Presently, using conventional equipment, the FBF may be advantageous where use of alternative fuels is possible.

MAINTENANCE

Maintenance and replacement requirements for major components of the MHF and FBF systems show no distinct advantages of one system over the other.

- Both MHF rabble arms and FBF air distribution systems are durable, and neither requires replacement for many years with ordinary maintenance. Although rabble arms are more exposed to abrasion and differential heating than FBF orifices, if properly designed and maintained, long service is attainable.

- Hearths in the MHF and refractory domes in the FBF are subject to cyclic temperature swings which can cause damage. The MHF experiences more frequent cycling than the FBF and is more prone to damage. In addition, the MHF has more hearths that must be repaired and replaced. Steady sludge feed and a reduction of shutdowns and startups can minimize maintenance in these refractory areas.

- If both types of furnaces use hydraulic ash handling systems, the general opinion is that there is no outstanding difference in maintenance between the two. Dry ash handling for the MHF is reported to require a considerable degree of maintenance. In the ash handling system of the FBF which carries both ash and bed media, the flue gas outlet is the source of erosion in flues and into the scrubber entrance.

- Exhaust gas systems for the FBF, including the heat exchanger and expansion joints, often are items of serious maintenance and require considerably more maintenance than does the exhaust system for the MHF. Corrosive attack is reported more often for the FBF exhaust system. Maintenance requirements for the induced draft fan in the MHF are not required for the FBF.

ELECTRIC POWER

Electric power for the two types of furnaces is required for the following major equipment based upon conventional operation: air blowers for the auxiliary fuel system, induced draft fan and furnace drive for the MHF, and fluidizing blowers and burners for the FBF. Assuming the MHF is typically operated at 100 percent excess air with burners set at 50 to 75 percent excess air and the FBF operates at 35 percent excess air with burners set at 25 percent excess air (typical conditions), electric power requirements are not significantly different between the two furnaces. Despite the considerably higher blower pressure required for the FBF, approximately half the air volume is handled compared to the MHF. In actual practice, electric power for the FBF is not significantly higher than for the MHF. However, air requirements for the FBF have been reported to be higher than predicted.

LABOR COST

For either type of furnace, a full-time operator is required when one furnace is operating. If two furnaces are operating, operator attention will increase similarly for either type of furnace requiring supplemental part-time help. The required skills for operators of either furnace are considered to be equal.

The FBF is more advantageous where one- or two-shift per day operations are preferred to 24-hour operation. The MHF performs more economically under continuous operation. Therefore, if furnace capacity exceeds sludge production or sludge dewatering is noncontinuous, the labor costs are more favorable for the FBF system.

INORGANIC CHEMICAL CONDITIONING

Lime and ferric chloride are frequently used as chemical aids in wastewater treatment processes and in sludge dewatering. Sludges containing metal salts from these processes have been burned with severe slagging and clinkering. Some FBF's that have burned municipal sludge containing ferric chloride from phosphorus removal have had slagging so severe as to plug the gas outlet from the reactor.

In both types of furnaces, sludges with chemical addition increase O&M costs, fuel consumption, and corrosion. Increased ash and clinkers from these chemicals result in higher operating and maintenance costs. Temperatures of hearths, beds, and freeboard areas must be carefully monitored and maintained to control slagging. The additional inert material from chemicals that are fed into the furnace also increases fuel consumption.

If calcining temperatures are reached, the endothermic reaction (with lime) requires additional energy. In addition, chlorides at elevated temperatures result in accelerated corrosion of metal parts.

These experiences have caused FBF manufacturers to research and investigate the reactions of these chemicals on reactor beds and to attempt to resolve the problems in reactor vessel cooling systems caused by chemical addition.

The use of polymers as dewatering aids with belt filter presses has been very effective, and their adoption in lieu of lime and ferric chloride has benefitted furnace operations. Some polymer conditioned sludges have been known to cause clinkers in MHF beds, but this condition does not appear to be common.

REFERENCES

1. U.S. Environmental Protection Agency, "Plant Scale Demonstration of Sludge Incinerator Fuel Reduction," EPA-600/2-83-083, March 1983.

2. U.S. Environmental Protection Agency, "Sewage Sludge Incinerator Fuel Reduction at Nashville, Tennessee," EPA-600/2-83-105, December 1981.

3. U.S. Environmental Protection Agency, "Sewage Sludge "EPA-600/2-84/146, March 1982.

4. U.S. Environmental Protection Agency, 1982 Needs Survey.

5. U.S. Environmental Protection Agency, "Municipal Sludge Combustion," Draft, July 1984.

6. U.S. Environmental Protection Agency, Questionnaires from selected POTW's, EPA Contract No. 68-03-3019.

7. U.S. Environmental Protection Agency, "Thermo Conversion of Municipal Wastewater Sludge, Phase II, Study of Heavy Metals Emissions," EPA Grant No. R804463, 1979.

8. Brown and Caldwell, "Central Contra Costa Sanitary District - Solid Waste Resource Recovery, Full Scale Test Report," March 1977.

RELATED MATERIAL

U.S. Environmental Protection Agency, "Process Design Manual for Sludge Treatment and Disposal," EPA-625/1-79-011, 1979.

Metcalf & Eddy, Inc., "Wastewater Engineering," McGraw-Hill, New York, NY, 1979.

North American Manufacturing Co., "Combustion Handbook," North American Manufacturing Co., 1978.

American Boiler Manufacturers Association, ABMA Standards.

U.S. Environmental Protection Agency, "Air Pollution Aspects of Sludge Incineration," EPA-625/4-75-009, June 1975.

U.S. Environmental Protection Agency, "Standards of Performance for Sewage Treatment Plants," Federal Register, Volume 39, Number 47, Subchapter C, Part 60, Subpart 0, March 8, 1974.

American Society for Testing Materials, "Test Method for Feasibility of Coal and Coke Ash," ASTM D-1857-68.

U.S. Environmental Protection Agency, "Assessment of Sludge Processing Problems at Selected POTW's," Draft, EPA Contract No. 68-03-3019, 1979.

APPENDIX

The following table alphabetically lists all the incineration facilities contained in the data base. Limitations on the data base are described in Section 4 of this report. A key to the abbreviations is provided below.

ABBREVIATION KEY

Type of Sludge Incinerated

P	Primary
W	Waste Activated
D	Digested

Type of Incinerator

MH	Multiple-Hearth Furnace
FBI	Fluid Bed Incinerator
MHFB	Multiple-Hearth Furnace and Fluid Bed Incinerator

Type of Sludge Dewatering

C	Centrifuge
VF	Vacuum Filter
FP	Filter Press

Type of Sludge Conditioning

TC	Thermal Conditioning
CC	Chemical Conditioning
PC	Polymer Conditioning

Waste Heat Recovery

WHR	Waste Heat Recovery System (Unspecified Type)
WHB	Waste Heat Boiler
HWB	Hot Windbox
NWHR	No Waste Heat Recovery System

Operating Status

OP	Operating
N	Not in Operation
IOP	Intermittent Operation

SLUDGE INCINERATION STUDY DATA

FACIITY	REGION	DESIGN FLOW (MGD)	ACTUAL FLOW (MGD)	SLUDGE HNDLNG TRAIN	OP STATUS	START DATE	SLUDGE CONDITIONING	SLUDGE DEWATERING	HRS/WK	DRY SOLIDS LBS/HR	% DRY SOLIDS	WET MASS LBS/HR
ANCHORAGE AK PT WORONZOF	10	34.00	24.	P MH VF WHB	OP	1971						
FAIRBANKS AK	10	08.00	4.	P MH FP	N	1961						
GIRDWOOD AK	10	00.80	00.14	MH VF	OP							
SKAGWAY AK	10	00.30	00.09	MH FP	OP							
CONWAY AR STONE DAM	6	06.00	03.06	MH C PC	OP							
LITTLE ROCK AR ADAMS FIELD	6	27.00	25.	MH VF	N							
N LITTLE ROCK AR FAULKNER LADE	6	12.00	04.13	P FBI C PC WHB	OP	1963						

SLUDGE INCINERATION STUDY DATA

FACIITY	REGION	DESIGN FLOW (MGD)	ACTUAL FLOW (MGD)	SLUDGE HNDLNG TRAIN	OP STATUS	START DATE	SLUDGE CONDITIONING	SLUDGE DEWATERING	HRS/WK	DRY SOLIDS LBS/HR	% DRY SOLIDS	WET MASS LBS/HR
BARSTOW CA BARSTO REGL	9	04.50	01.80	P FBI C PC	N	1967						
CASTRO VLY CA ORO LOMA SD	9	20.00	09.00	MH VF	OP							
CONCORD CA WALNUT CREEK	9		35.	MH WHR	N							
CONTRA COSTA CA CENTRAL	9			PW MH C WHR	N	1978	LIME	4, TWO-STAGE VRT CNT FILTERS 2 ARE STANDBY		3000	22.5%	13333
FAIRFIELD CA	9			P FBI	N	1965						
FOSTER CITY CA	9			P FBI	N	1968						
LAKE ARROWHEAD CA	9	01.70	01.10	MH VF	OP							

SLUDGE INCINERATION STUDY DATA

FACIITY	REGION	DESIGN FLOW (MGD)	ACTUAL FLOW (MGD)	SLUDGE HNDLNG TRAIN	OP STATUS	START DATE	SLUDGE CONDITIONING	SLUDGE DEWATERING	HRS/WK	DRY SOLIDS LBS/HR	% DRY SOLIDS	WET MASS LBS/HR
MARTINEZ CA CTL CNTRA CSTA	9	40.00	36.16	MH	OP							
MONTEREY CA	9		9.	MH	N							
OXNARD CA	9			P MH	N	1971						
PALO ALTO CA PALO ALTO REGL	9	30.60	26.42	MH C PC NWHB	OP	1970			168	1000	4.5%	22222
PORT HUENEME CA	9			P FBI	N	1964						
REDWOOD CITY CA	9	24.	22.	FBI FP CC HWB	OP	1981	18% LIME 6% FERRIC CHLORIDE	2-47 PLATE HOESCH FP. RUNS WELL.		4000	40.0%	10000
RICHARDSON BAY CA TRESIZE GLEN	9		0.1	FBI	N							

SLUDGE INCINERATION STUDY DATA

FACIITY	REGION	DESIGN FLOW (MGD)	ACTUAL FLOW (MGD)	SLUDGE HNDLNG TRAIN	OP STATUS	START DATE	SLUDGE CONDITIONING	SLUDGE DEWATERING	HRS/WK	DRY SOLIDS LBS/HR	% DRY SOLIDS	WET MASS LBS/HR
RICHMOND CA	9	16.00	06.90	PWD MH	N	1968						
S. BAYSIDE CA	9		19.	FBI WHB	OP							
S. LAKE TAHOE CA S. TAHOE	9	07.50	05.60	MH C PC WHB	OP							
SACRAMENTO CA	9	138.	136.	MH C WHB	OP	1983						
SAN BERNARDINO CA WWTF NO. 2	9		14.	PWD FBI TC	OP	1970						
SAN CLEMENTE CA	9	04.00	02.83	MH VF	OP							
SAN LEANDRO CA	9	11.00	9.	MH C PC	N							

SLUDGE INCINERATION STUDY DATA

FACIITY	REGION	DESIGN FLOW (MGD)	ACTUAL FLOW (MGD)	SLUDGE HNDLNG TRAIN	OP STATUS	START DATE	SLUDGE CONDITIONING	SLUDGE DEWATERING	HRS/WK	DRY SOLIDS LBS/HR	% DRY SOLIDS	WET MASS LBS/HR
SAN MATEO CA	9	13.6	12.	MH VF TC WHB	IOP	1979	3 ZIMPRO 300 PSI 365 DEGF 2 ARE STANDBY	2-CLOTH ENVIREX VF - ONE IS STANDBY		1200	42.0%	2857
SANTA CRUZ CA E CLIFF SAN DST CA	9			P FBI	N	1963						
TRUCKEE CA TAHOE-TRUCKEE	9	05.08	04.30	MH FP	OP							
YOSEMITE NTL PK CA	9		2.	PW MH VF	IOP	1975						
AVON CO UPR EAGLE VLY	8	03.10	01.88	MH VF	OP							
LAKEWOOD CO S. LAKEWOOD	8	02.30	01.40	MH VF	OP							
VAIL CO	8	01.50	01.45	MH VF	IOP							

SLUDGE INCINERATION STUDY DATA

FACIITY	REGION	DESIGN FLOW (MGD)	ACTUAL FLOW (MGD)	SLUDGE HNDLNG TRAIN	OP STATUS	START DATE	SLUDGE CONDITIONING	SLUDGE DEWATERING	HRS/WK	DRY SOLIDS LBS/HR	% DRY SOLIDS	WET MASS LBS/HR
BRIDGEPORT CT EASTSIDE	1	12.00	09.54	MH VF	N							
BRIDGEPORT CT WESTSIDE	1	30.00	20.	MH VF	N							
CROMWELL CT MATTABASSETT	1	30.00	19.	MH VF NWHR	OP	1968					30.0%	
GLASTONBURY CT	1	03.46	1.	MH C PC	N							
GROTON CT	1	05.00	02.34	PW MH C PCTC	OP	1972	BSP HEAT TMT					
HARTFORD CT	1	60.00	48.	PW MH VFFP NWHR	OP	1971				3750	21.2%	17688
KILLINGLY CT	1	08.00	01.92	PS MH VF	OP	1973						

SLUDGE INCINERATION STUDY DATA

FACIITY	REGION	DESIGN FLOW (MGD)	ACTUAL FLOW (MGD)	SLUDGE HNDLNG TRAIN	OP STATUS	START DATE	SLUDGE CONDITIONING	SLUDGE DEWATERING	HRS/WK	DRY SOLIDS LBS/HR	% DRY SOLIDS	WET MASS LBS/HR
MIDDLETOWN CT	1	10.20	03.68	PW MH VF	N	1973						
NAUGATUCK CT	1	10.30	02.64	PS MH	OP	1973						
NEW HAVEN CT EAST SHORE	1	40.00	9.	PW MH VFC PCTC MWHR	OP		2 ZINPRO					
NEW HAVEN CT EAST ST	1	25.00	13.83	MH VF	OP							
NEW LONDON CT	1		3.	PS MH MWHR	OP	1976						
NORWALK CT	1	15.00	09.00	PW FBI C TC WHR	OP	1972						
SIMSBURY CT	1	02.85	00.98	MH VF	OP							

SLUDGE INCINERATION STUDY DATA

FACIITY	REGION	DESIGN FLOW (MGD)	ACTUAL FLOW (MGD)	SLUDGE HNDLNG TRAIN	OP STATUS	START DATE	SLUDGE CONDITIONING	SLUDGE DEWATERING	HRS/WK	DRY SOLIDS LBS/HR	% DRY SOLICS	WET MASS LBS/HR
SO WINDSOR CT	1	03.75	01.27	P FBI C PC	OP	1967						
STAFFORD CT	1	02.00	01.42	PW MH VF	OP	1971						
STRATFORD CT	1	11.50	08.65	MH FP PC	OP			BELT FILTER PRESS				
THOMPSONVILLE CT ENFIELD	1	10.00	04.15	MH VF	OP							
TORRINGTON CT TORRINGTON MAIN	1	07.00	05.98	PW FBI VF	N	1968						
VERNON CT ROCKVILLE	1	06.42	2.	MH VF MWHR	OP							
WATERBURY CT	1	25.00	22.	PW MH VF MWHR	OP	1971						

SLUDGE INCINERATION STUDY DATA

FACIITY	REGION	DESIGN FLOW (MGD)	ACTUAL FLOW (MGD)	SLUDGE HNDLNG TRAIN	OP STATUS	START DATE	SLUDGE CONDITIONING	SLUDGE DEWATERING	HRS/WK	DRY SOLIDS LBS/HR	% DRY SOLIDS	WET MASS LBS/HR
WEST HAVEN CT	1	10.40	12.70	PW FBI VF	N	1971						
WILLAMANTIC CT	1	05.50	02.59	MH VF NWHR	N							
WILMINGTON DE DE RECL PROJ	3			MH	OP							
JACKSONVILLE FL BUCKMAN ST	4	43.	30.	PW MH VF TC WHB	N	1978	3 BSP HEAT TMT	4-EIMCO CLOTH VF		7000	20.0%	35000
PENSACOLA FL MAIN ST	4	20.00	8.	MH VFC PC NWHR	OP							
ATLANTA GA R.M. CLAYTON	4			MH C PC NWHR	OP	1974			120		3.7%	
ATLANTA GA UTOY CREEK	4	30.00	29.60	PD MH VF NWHR	OP	1973						

SLUDGE INCINERATION STUDY DATA

FACIITY	REGION	DESIGN FLOW (MGD)	ACTUAL FLOW (MGD)	SLUDGE HNDLNG TRAIN	OP STATUS	START DATE	SLUDGE CONDITIONING	SLUDGE DEWATERING	HRS/WK	DRY SOLIDS LBS/HR	% DRY SOLIDS	WET MASS LBS/HR
DECATUR GA POLE BRIDGE	4	03.00	01.60	MH FP	OP							
DECATUR GA SNAPFINGER CR	4	21.50	16.00	PW MH VF	OP	1973						
JONESBORO GA R.L. JACKSON	4	04.50	01.10	MH FP	OP							
LOVEJOY GA SHOAL CREEK	4	01.10	00.41	MH VF	OP							
SAVANNAH GA PRESIDENT ST	4	20.00	18.	PW MH FP NWHR	OP	1972						
SMYRNA GA CHATTAHOOCHEE COBB CTY	4	20.00	17.	PW MH FP NWHR	OP	1977						
SMYRNA GA R.L. SUTTON	4			MH FP NWHR	OP				168	1667	40.0%	4167

SLUDGE INCINERATION STUDY DATA

FACIITY	REGION	DESIGN FLOW (MGD)	ACTUAL FLOW (MGD)	SLUDGE HNDLNG TRAIN	OP STATUS	START DATE	SLUDGE CONDITIONING	SLUDGE DEWATERING	HRS/WK	DRY SOLIDS LBS/HR	% DRY SOLIDS	WET MASS LBS/HR
HONOLULU HI HONOULIULI	9	25.00	3.0	MH C PCTC WHB	OP	1984	2-ZIMPRO	3-BYRD CENTRIFUGES 2 ARE STANDBY				
HONOLULU HI SAND IS	9	82.	62.	MH C PCTC WHB	OP	1980	2-ZIMPRO, 400 PSI 380 DEGF 1 IS STANDBY	3 BYRD CENTRIFUGES 2 ARE STANDBY	168	1995	28.5%	7000
CEDAR RAPIDS IA	7	42	25.	PW MH VF TC WHB	OP	1980	3 ZIMPRO, 350 PSI 375 DEGF 1 IS STANDBY	3 EIMCO CLOTH VF 1 IS STANDBY		4000	45.0%	8888
DAVENPORT IA	7	26.00	19.30	PW MH VF TC WHB	OP	1980	2 ZIMPRO, 350 PSI 375 DEGF NO STANDBY	2 EIMCO CLOTH VF 1 IS STANDBY		1875	50.0%	3750
DES MOINES IA HIGHLAND HILLS	7	00.52	00.77	MH	N							
DUBUQUE IA	7	15.33	09.35	P PBI FP PCTC WHB	OP	1970	ZIMPRO WILL BE REPLACED BY BELT FILT PRSS	2 EIMCO BELT FILTER PRESSES		1600	30.0%	5333
GRAND JCT IA	7	00.08	00.07	MH	N							

FACIITY	REGION	DESIGN FLOW (MGD)	ACTUAL FLOW (MGD)	SLUDGE HNDLNG TRAIN	OP STATUS	START DATE	SLUDGE CONDITIONING	SLUDGE DEWATERING	HRS/WK	DRY SOLIDS LBS/HR	% DRY SOLIDS	WET MASS LBS/HR
NEWTON IA NEWTON SW	7	00.25	00.29	MH	N							
PLEASANT HILL IA	7	00.40	00.16	MH VF	N							
SIOUX CITY IA	7	17.50	18.55	MH VF	OP							
TROY MILLS IA	7	00.02	00.01	MH	N							
URBANDALE IA BEAVER CREEK	7	00.40	00.33	MH	N							
DANVILLE IL	5			PWD MH	N	1975						
DECATUR IL	5		25.	MH NWHR	OP							

SLUDGE INCINERATION STUDY DATA

FACIITY	REGION	DESIGN FLOW (MGD)	ACTUAL FLOW (MGD)	SLUDGE HNDLNG TRAIN	OP STATUS	START DATE	SLUDGE CONDITIONING	SLUDGE DEWATERING	HRS/WK	DRY SOLIDS LBS/HR	% DRY SOLIDS	WET MASS LBS/HR
GRANITE CITY IL	5		7.	P MH VF TC WHB	N	1976	2 BSP HEAT TRT 1 IS STANDBY NOT IN USF	2 KOMLINE SANDERSON VFS IN USE				
MISHAWAKA IL	5	12.00	11.11	MH VF	OP							
ROCK FALLS IL	5	01.81	01.80	P MH VF	N	1963						
ROCKFORD IL	5	60.20	39.06	MH VF	N							
EAST CHICAGO IN	5	20.00	15.	MH VF	IOP							
ELKART IN	5	20.00	14.80	MH	OP							
INDIANAPOLIS IN BELMONT ST #1	5		125.	MH NWHR	OP							

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FACIITY	REGION	DESIGN FLOW (MGD)	ACTUAL FLOW (MGD)	SLUDGE HNDLNG TRAIN	OP STATUS	START DATE	SLUDGE CONDITIONING	SLUDGE DEWATERING	HRS/WK	DRY SOLIDS LBS/HR	% DRY SOLIDS	WET MASS LBS/HR
PORTAGE IN	5			PW MH	N	1970						
KANSAS CITY KS KAW PT.	7	35.	25.	P FBI C PC WHB	OP	1978	POLYMER	16-MERCO BOWL C		2222	35.0%	6348
KANSAS CITY KS NO. 20	7	07.	02.5-03	PWD FBI C PC WHB	OP	1979	POLYMER	3-MERCO BOWL C		400	25.5%	1568
LENEXA KS LITTLE MILL CRK	7	0C.60	00.56	MH	OP							
OVERLAND PK KS INDIAN CK MD BS	7	03.00	00.01	MH VF	OP							
SHAWNEE MSN KS TURKEY CRK #1 JOHNSON CTY WD	7		6.	PW MH VF NWHR	OP	1976			80	1500	20.0%	7500
BROMLEY KY DRYCREEK	4	3C.00	24.	MH FP WHB	N							

SLUDGE INCINERATION STUDY DATA

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CAMPBELL KY KENTON CTY COVINGTN-DRY CK	4	30.		PW MH VF TC WHB	N	1979	2 ZIMPRO, 350 PSI, 380 DEGF 1 IS STANDBY	3 EIMCO CLOTH VF		1969	45.0%	4375
LOUISVILLE KY MORRIS FORMAN JEFFERSON CTY	4	105	88.	PW MH VF TC WHB	N	1977	4 ZIMPRO, 325 PSI, 375 DEGF	4 KOMLINE-SANDERSON VF		8333	35.0%	23808
LAKE CHARLES LA PLANT B	6	02.25	02.20	MH C PC NWHR	OP							
LAKE CHARLES LA PLANT C	6	04.00	02.90	MH C PC NWHR	OP							
METAIRIE LA W. NAPOLEON #1	6	02.50	03.00	MH C PC	OP							
NATCHITOCHES LA	6			P FBI	N	1966						
NEW ORLEANS LA EAST BANK	6	122.00	70.60	MHFB C PC	OP							

SLUDGE INCINERATION STUDY DATA

FACIITY	REGION	DESIGN FLOW (MGD)	ACTUAL FLOW (MGD)	SLUDGE HNDLNG TRAIN	OP STATUS	START DATE	SLUDGE CONDITIONING	SLUDGE DEWATERING	HRS/WK	DRY SOLIDS LBS/HR	% DRY SOLIDS	WET MASS LBS/HR
NEW ORLEANS LA WEST BANK	6	10.00	12.30	MH VF NWHR	OP							
ATTLEBORO MA	1		4.	PW MH FP WHR	OP	1977						
BROCKTON MA	1			MH	N							
CHICOPEE MA	1	15.50	5.	PW MH VF NWHR	OP	1975						
FALL RIVER MA	1	21.00	21.00	MH FP PC	OP			BELT FILTER PRESS				
FITCHBURG MA EAST	1	12.40	1.	MH VF	IOP	1973						
HULL MA	1	03.07	00.45	MH C PC	N							

SLUDGE INCINERATION STUDY DATA

FACIITY	REGION	DESIGN FLOW (MGD)	ACTUAL FLOW (MGD)	SLUDGE HNDLNG TRAIN	OP STATUS	START DATE	SLUDGE CONDITIONING	SLUDGE DEWATERING	HRS/WK	DRY SOLIDS LBS/HR	% DRY SOLIIS	WET MASS LBS/HR
LYNN MA	1			FBI WHB	N	1981						
N. ANDOVER MA GRTR LWRNCE SD	1		38.	MH VFFP NWHR	OP	1977		BELT FILTER PRESS	168		25.0%	
NEW BEDFORD MA	1	45.50	39.10	P MH C PC	OP	1971						
QUINCY MA NUT IS	1	112.00	127.75	MH	IOP	1961						
SALEM MA SOUTH ESSEX	1	41.00	22.70	PW MH C PC	N	1974						
SWAMPSCOTT MA	1	02.20	01.75	P FBI C PC	N	1971						
WORCESTER MA UPR BLACKSTN RG	1	56.00	32.30	MH C PC NWHR	OP							

SLUDGE INCINERATION STUDY DATA

FACIITY	REGION	DESIGN FLOW (MGD)	ACTUAL FLOW (MGD)	SLUDGE HNDLNG TRAIN	OP STATUS	START DATE	SLUDGE CONDITIONING	SLUDGE DEWATERING	HRS/WK	DRY SOLIDS LBS/HR	% DRY SOLIDS	WET MASS LBS/HR
ANNAPOLIS MD ANNE ARUNDEL CY	3	10.00	4.	MH C PCTC NWHR	OP	1977	1 BSP, 220 PSI 365 DEGF	2 SHARPLES CENTRIFUGES 1 IS BACKUP	140	1200	35.0%	3428
BALTIMORE MD COX CREEK ANNE ARUNDEL CY	3	15.9	8.	PW MH C TC NWHR	OP	1976	1 BSP, 260 PSI, 350 DEGF	2 SHARPLES CENTS-USING BELT FP SOON		4550	32.5%	14000
BALTIMORE MD PATAPSCO WWTP	3			P MH FP CC	IOP	1982	11% LIME 5% FERRIC CHLORIDE	8 EDWARD & JONES FILTER PRESSES		35700	35.0%	102000
BALTIMORE MD PISCATAWAY	3			MH NWHR	OP							
CHURCHTON MD BROADWATER WWTP ANNE ARUNDEL CY	3	02.00	00.39	FBI C PC	OP	1971						
OCEAN CITY MD	3	17.4	7.	P FBI VF PC	OP	1980	POLYMER	MERCO BOWL C		350	30.5%	1147
PARKWAY MD PARKWAY STP	3			PW FBI	N	1974				2360	20.0%	11800

SLUDGE INCINERATION STUDY DATA

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PERRYMAN MD SOD RUN	3	10.00	02.87	MH VF TC	OP							
WASHINGTON MD WESTERN BRANCH UPPER MARLBORO	3	30.	22.	PW MH C PCTC	IOP	1977	2 ZIMPRO, 250 PSI 325 DEGF 1 IS STANDBY	3 SHARPLES CENTRIFUGES 2 ARE STANDBY		583	27.5%	2120
ROCKLAND ME	1	02.80	01.82	MH VF	OP							
ANN ARBOR MI CY OF ANN ARBOR	5	29.5	16.	MH FP CC WHB	OP	1983	15% LIME 5% FERRIC CHLORIDE	3 PASSAVANT FILTER PRESSES 1 IS STANDBY		3333	40.0%	8332
ANN ARBOR MI YPSI COMMUNITY	5	28.90	10.	MH WHR	OP							
BATTLE CREEK MI	5			D MH	N	1960						
BAYCITY MI	5	13.27	12.	MH VF CC NWHR	OP	1978	LIME & FERRIC CHLORIDE		80	833	40.0%	2082

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CHELSEA MI	5	00.40	00.65	MH	OP							
DELTA MI	5			PW MH	N	1970						
DETROIT MI	5	840.00	698.	MH VF MWHR	OP							
DETROIT MI WYANDOTTE	5	75.00	78.48	MH VFC PC	OP							
E. LANSING MI	5	18.75	11.27	PW MH VF WHR	OP	1974						
ESSEXVILLE MI ESSEXVILLE	5	00.75	00.96	MH	OP							
FLINT MI	5	50.00	43.30	PW MH VF TC	N	1976	3 ZIMPRO, 320 PSI 380 DEGF	2 KOM-SAND 4 FIMCO, ONLY RUN 1 OF 6		3520	32.0%	11000

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FLINT MI	5	20.00	20.67									
MONTROSE DST 2				MH VF	OP							
GENESEE MI	5		42.	PS MH	N	1973						
GRAND HAVEN MI	5	05.00	03.02	PW MH VF TC	N	1972	ZIMPRO					
GRAND RAPIDS MI	5	66.00	50.	PW MH VF TC WHB	OP	1979	2 ZIMPRO, 385 PSI 380 DEGF	4 FNVIREX CLOTH VF		1500	45.0%	3333
GRANDVILLE MI	5	19.00	12.90									
WYOMING CTY				MH VF	N							
HOLLAND MI	5	09.00	04.93	PW FBI C PC	N	1970						
KALAMAZOO MI	5	45.0	33	PW MH VF TC WHB	OP	1971	3 ZIMPRO	3 KOHLINE-SANDERSON VF 1 IS STANDBY		2933	44.0%	6665

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LANSING MI	5	40.5	25.13	MH VF TC WHB	N	1976	2 ZIMPRO, 300 PSI 400 DEGF	2 FNVIREX CLOTH VF 1 IS STANDBY		3300	55.0%	6000
NILES MI NILES WWTP	5	11.00	4.	MH VF TC WHB	IOP	1978	ZIMPRO, 400 PSI 370 DEGF					
OWOSSO MI	5	06.00	3.	MH FP NWHR	OP							
PONTIAC MI PONT SEW TRT DV	5	25.50	20.	D MH VF CC NWHR	OP	1963	LIME & FERRIC CHLORIDE		86	972	7.8%	12461
PT HURON MI	5	33.00	13.87	PW FBI C PCTC	OP	1972						
SAGINAW MI	5	32.70	30.22	MH VF	OP							
SAGINAW MI SW DST SAG TWP	5	01.50	04.29	MH VF	N							

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TRENTON MI	5	05.50	05.60	MH NWHR	OP							
WARREN MI	5			PW MH	M	1971						
WATERVLIET MI PAW PAW LAKE	5	03.50	01.28	P MH FP PC	M	1971						
WYANDOTTE MI WAYNE CTY	5		45.	P MH NWHR	OP	1962						
WYOMING MI	5			PW MH VF	M	1973						
DULUTH MN WLSSD REGL	5	43.63	35.28	FBI VF WHB	OP	1978				6038	21.0%	28752
EAGAN MN SENECA	5	24.00	10.34	MH VF CC NWHR	OP	1972	LIME & FERRIC CHLORIDE		168	61	21.0%	290

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MINNPLS-ST PAUL MN METROPOLITAN	5	290.	250.	PWD MH VFFP PCTC WHB	OP	1982	8 ZIMPRO, 400 PSI 370 DEGF 4 ARE STANDBY	8-44 PLATE ING- RAND PRESSES 4 ARE STANDBY		4875	45.0%	10833
CAPE GIRARDEAU MO	7	07.00	05.41	MH	OP							
INDEPENDENCE MO ROCK CREEK	7	07.5	5.0	PW FBI VF TC	OP	1979	1 ZIMPRO, 300 PSI 380 DEGF	3 KOHLINE- SANDERSON VF 1 IS STANDBY		2500	40.0%	6250
JEFFERSON CITY MO	7	06.20	05.97	P FBI VF	OP	1968						
KANSAS CITY MO BIG BLUE RIVER	7	85.00	67.00	MH VF	OP							
MONROE CITY MO	7	00.80	00.26	MH	OP							
ST CHARLES MO ST CHAS MO RIV	7	03.00	02.27	MH VF	N							

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ST CHARLES MO ST CHAS MS RIV	7	05.50	03.16	MH FP	OP							
ST LOUIS MO BISSELL PT	7	248.00	140.	P MH VF MWHR	OP	1965						
ST LOUIS MO LEMAY	7	125.00	110.	P MH VF WHR	OP	1968			168	4075	29.0%	14051
NATCHEZ MS	4	05.00	02.16	MH	OP							
BUTTE MT SILVER BOW CTY	8	08.00	07.72	MH	OP							
OMAHA NB PAPILLION CREEK	7			PS FBI	N	1977				7620	30.0%	25400
PLATTSMOUTH NB	7	1.50	00.72	MH	OP							

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GREENSBORO NC N BUFFALO	4	18.00	10.	MH VF WHB	OP	1984						
ROCKY MT. NC	4		10.	MH	OP							
SHELBY NC	4	06.00	03.66	FBI VF WHB	OP	1964						
WAYNESVILLE NC	4			PS FBI WHB	N	1964						
CONCORD NH WBB LACONIA	1	04.50	02.90	MH VF	OP							
GOFFSTOWN NH	1	00.37	00.24	MH	OP							
LEBANCN NH	1	01.67	01.19	PW MH C PC NWHR	OP	1977				656	22.0%	2981

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MANCHESTER NH MANCHESTER WWTF	1	26.00	17.81	MH C PC NWHR	OP	1977			114	1972	18.6%	10602
MERRIMACK NH MERRIMACK WWTP	1	05.00	02.33	MH VF NWHR	OP	1977			84	1800	15.0%	12000
NASHUA NH	1	19.50	12.67	MH VF	OP							
ASBURY PARK NJ	2	05.50	03.00	MH	OP							
ATLANTIC CITY NJ ATLANTIC CY REG	2	40.00	18.37	MH C TC WHB	OP	1980	2 BSP, 300 PSI 380 DEGF 1 IS STANDBY	3 SHARPLES CENTRIFUGES 1 IS STANDBY		2000	32.5%	6153
BAYONNE NJ	2	21.00	11.12	MH VF	OP							
BERKELEY NJ CENTRAL	2	24.00	2.95	MH C PC	OP							

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BRIDGEWATER NJ SOMST-RARITAN	2	10.00	07.00	MH C PC	OP							
BURLINGTON NJ	2			P MH	N	1964						
CEDAR GROVE NJ	2	01.50	01.00	MH VF	OP							
CINNAMINSON NJ	2	02.00	01.17	MH VF	OP							
DEAL NJ DEAL BOROUGH	2	00.28	00.42	MH	OP							
ELIZABETH NJ JT MEET	2	75.00	52.00	MH VF	OP							
FREEHOLD NJ FREEHOLD BORO	2	01.50	01.61	MH	OP							

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GLOUCESTER CTY NJ	2			PW FBI TC	N	1971						
HOBOKEN NJ	2	20.80	15.05	MH	OP							
JERSEY CITY NJ EAST SIDE	2	46.62	27.70	MH	N							
JERSEY CITY NJ WEST SIDE	2	36.00	19.91	MH VF	OP							
LINDEN NJ LINDEN ROSELLE	2	12.50	10.30	MH	OP							
LIVINGSTON NJ	2	04.20	02.70	MH VF	OP							
MARLBORO NJ CENTRAL JERSEY	2	.48	.30	MH	OP							

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MAYS LANDING NJ	2	00.5	00.55	MH	OP							
MEDFORD NJ	2	01.00	01.17	MH VF	OP							
MEDFORD LAKES NJ	2	00.55	00.39	MH VF TC	OP							
MOUNT HOLLY NJ RANCOCAS ROAD	2	05.00	01.51	MH VF	OP							
NEPTUNE NJ S MONMOUTH REG	2	09.10	2.92	MH	OP							
NEW PROVIDENCE NJ	2	06.00	00.93	MH	OP							
NEWARK NJ PASSAIC VALLEY	2	300.		P MH FP TC WHR	N	1971	12 ZIMPRO					

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NEWTON NJ	2	01.00	00.83	MH VF TC	OP							
PALMYRA NJ PALMYRA BORO	2	00.53	00.55	MH VF TC	OP							
PARSIPPANY NJ TROY HILLS	2		16.	P MH	OP	1974						
PLEASANTVILLE NJ	2			P FBI WHB	N	1965						
PRINCETON NJ SBRSA #1	2	10.00	4.	MH FP PC	OP			BELT FILTER PRESS				
SAYREVILLE NJ	2		120.	MH	OP							
SECAUCUS NJ	2	02.25	01.07	MH	OP							

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SOUTH KEARNY NJ KEARNY IND	2	04.00	01.80	MH	OP							
STANHOPE NJ MUSCONETCONG	2	01.00	00.88	MH VF	OP							
TOMS RIVER NJ SOUTHERN	2	20.00	04.47	MH C PC	OP							
TOTOWA NJ RIVERVIEW DRIVE	2	01.10	01.21	MH VF	OP							
TWO BRIDGES NJ PEQUANNOCK	2			PW FBI HWB	N	1975						
UNION BEACH NJ BAYSHORE REGL	2	08.00	08.46	MH C PC	OP							
WALDWICK NJ NW BERGEN CTY	2			PS FBI WHB	N	1967						

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WAYNE NJ MT VIEW WPCP	2		24.	MH VF PC NWHR	OP	1977				6200	17.5%	35428
CARSON CITY NV	9	03.75	03.34	P MH C PC	N	1972						
DOUGLAS CITY NV ZEPHYR COVE SID #1	9		1.	MH NWHR	OP							
LAKE TAHOE NV ROUND HILL	9			PW FBI WHB	N	1966						
LAS VEGAS NV CLARK COUNTY CCSD NO. 1	9	32.	25.	P MH VF TC WHB	N	1971	ZIMPRO, 300 PSI 350 DEGF	2 ENVIREX CLOTH VF 1 IS STANDBY		2912	35.0%	8320
ALBANY NY NORTH	2			PW MH VF	OP	1971						
ALBANY NY SOUTH	2	20.00	19.80	MH VF	OP							

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AMHERST NY	2		8.	W MH VFC WHB	OP	1976	LIME					
ARLINGTON NY	2			PW FBI	N	1968						
AUBURN NY	2	09.30	09.57	PW MH VF	N	1971						
BATH NY	2			PW FBI	N	1969						
BEACON NY	2	06.00	03.93	PWD MH VF	OP	1970						
BRIARCLF MANOR NY RIVER RD	2	00.04	00.04	MH	N							
BRIARCLF MANOR NY SCARBCRO DOCK	2	00.17	00.11	MH	N							

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BUFFALO NY BIRDS IS	2	180.	178.	PW MH FP PC WHB	OP	1979		2 KOESTER BELT FILTER PRESSES		42000	16.5%	254545
CAMILIUS NY	2	00.20	00.52	MH	OP							
CANAJOHAIRE NY	2	02.85	00.54	P MH C PC	N	1963						
CELORON NY S CHAUTAUQUA LK	2	04.10	01.12	MH VF	OP							
CORLAND NY	2	10.00	05.98	MH VF	N							
CROTON-ON-HUDSN NY	2	00.75	01.04	MH	N							
DUNKIRK NY DUNKIRK STP	2	6.00	6.03	PS MH VF CC NWHB	OP	1975	LIME & FERRIC CHLORIDE		120	2083	12.0%	17358

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ELMA CENTER NY ELMA MDWS SUBD	2	00.05	00.04	FBI VF	OP							
FISHKILL NY BROCKWAY SSA #3	2	00.08	00.10	MH	OP							
GREECE NY N W QUADRANT TP	2	15.00	11.	MH C PC	OP							
HALFMOON NY SARATCGA CSD1	2	13.00	00.79	MH VF	OP							
HAMBURG NY SOUTHTOWNS SD3	2	16.00	05.42	PW FBI VFC PC WHB	OP	1978	LIME & FERRIC CHLORIDE					
LAWRENCE NY	2	01.50	01.34	MH	OP							
LIBERTY NY	2	01.60	01.06	P MH	OP	1966						

SLUDGE INCINERATION STUDY DATA

FACIITY	REGION	DESIGN FLOW (MGD)	ACTUAL FLOW (MGD)	SLUDGE HNDLNG TRAIN	OP STATUS	START DATE	SLUDGE CONDITIONING	SLUDGE DEWATERING	HRS/WK	DRY SOLIDS LBS/HR	% DRY SOLIDS	WET MASS LBS/HR
LIMA NY	2	00.20	00.11	MH	OP							
LITTLE FALLS NY	2			PW FBI	N	1970						
MAMARONECK NY	2	18.00	15.	MH VF	OP							
MARION NY MARION SAN SS	2	0C.13	00.11	FBI VF	OP							
MENANDS NY NORTH ALBANY	2	35.00	19.00	MH VF	OP							
MONROE CTY NY	2			PD MH	N	1972						
NEW ROCHELLE NY WESTCHESTER CTY	2	15.00	16.30	PW MH VF TC WHB	O	1981	2 ZIMPRO, 350 PSI 390 DEGF 1 IS STANDBY	2 KOMLINE-SANDERSON VF 1 IS STANDBY	168	1000	30.0%	3333

SLUDGE INCINERATION STUDY DATA

FACIITY	REGION	DESIGN FLOW (MGD)	ACTUAL FLOW (MGD)	SLUDGE HNDLNG TRAIN	OP STATUS	START DATE	SLUDGE CONDITIONING	SLUDGE DEWATERING	HRS/WK	DRY SOLIDS LBS/HR	% DRY SOLIDS	WET MASS LBS/HR
NEW WINDSOR NY	2	05.00	03.50	P FBI C PC NWHR	N	1968						
NEWBURGH NY COLDEN PARK SD	2	00.10	00.09	MH	OP							
NIAGARA CO. NY NO. 1	2	14.0	3.5	W MH VF TC	N	1978	2 ZIMPRO, 300 PSI 390 DEGF	3 EIMCO CLOTH VF 1 IS STANDBY		1000	40.0%	2500
OLEAN NY	2	05.00	04.05	MH C PC	OP							
ORANGEBURG NY ORANGETOWN DPW	2	08.50	07.20	MH VF PC NWHR	OP	1968	CATIONIC & ANIONIC POLYMER		84	531	6.0%	8850
OSSINING NY	2	02.00	01.62	MH	OP							
OSWEGO NY EAST SIDE	2		3.	MH VF NWHR	OP	1971			72	417	25.0%	1668

SLUDGE INCINERATION STUDY DATA

FACIITY	REGION	DESIGN FLOW (MGD)	ACTUAL FLOW (MGD)	SLUDGE HNDLNG TRAIN	OP STATUS	START DATE	SLUDGE CONDITIONING	SLUDGE DEWATERING	HRS/WK	DRY SOLIDS LBS/HR	% DRY SOLIDS	WET MASS LBS/HR
OSWEGO NY WEST SIDE	2		4.	MH VF PC MWHR	OP	1979			36	3000	16.5%	18181
PLEASANT VALLEY NY NOXON KNOLLS SD	2	00.03	00.02	MH	OP							
PLEASANT VALLEY NY TITUSVILLE SD	2	00.17	00.10	MH	OP							
POUGHKEEPSIE NY	2	08.00	03.30	PW MH C TC	OP		ZIMPRO					
POUGHKEEPSIE NY ARLINGTON SD	2	04.00	03.95	MH VF	OP							
PT BYRON NY	2	00.18	00.08	FBI VF	OP							
PT CHESTER NY	2	06.00	07.79	MH VF TC	OP							

SLUDGE INCINERATION STUDY DATA

FACIITY	REGION	DESIGN FLOW (MGD)	ACTUAL FLOW (MGD)	SLUDGE HNDLNG TRAIN	OP STATUS	START DATE	SLUDGE CONDITIONING	SLUDGE DEWATERING	HRS/WK	DRY SOLIDS LBS/HR	% DRY SOLIDS	WET MASS LBS/HR
PT WASHINGTON NY	2	03.0	03.37	P FBI C PC	OP	1968						
RETSOF NY RETSOF SD	2	00.03	00.05	MH	OP							
ROCHESTER NY ALLENS CREEK	2		9.	MH	N							
ROCHESTER NY F E VAN LARE	2	100.00	69.00	MH VF	OP							
ROCHESTER NY GATES CHILI OCD	2	15.00	11.95	MH VF	OP							
SARATCGA CTY NY DISTR. NO. 1	2			FBI	N	1977				638	22.0%	2900
SCHENECTADY NY	2	16.30	13.59	MH VF	OP							

SLUDGE INCINERATION STUDY DATA

FACIITY	REGION	DESIGN FLOW (MGD)	ACTUAL FLOW (MGD)	SLUDGE HNDLNG TRAIN	OP STATUS	START DATE	SLUDGE CONDITIONING	SLUDGE DEWATERING	HRS/WK	DRY SOLIDS LBS/HR	% DRY SOLIDS	WET MASS LBS/HR
SOUTH DOWNS NY EIRIE CTY	2	15.	10.	W FBI FP CC WHB	OP	1980	12% LIME 6% FERRIC CHLORIDE	2 MANOR PLATE & FRAME FILTER PRESSES		833	30.0%	2776
SOUTHAMPTON NY DISP DISTR 15	2		30.	MH	OP							
SUFFERN NY SUFFERN VILLAGE	2	01.50	01.13	MH VF	OP							
SUFFOLK CO. NY	2	3C.	8.	MH VF TC WHB	OP	1982	2 ZIMPRO 1 IS STANDBY	3 ING-BAND VF 1 IS STANDBY		300	40.0%	750
SYLVAN BEACH NY E ONEIDA LAKE	2	02.00	00.89	MH VF	OP							
SYRACUSE NY LEY CREEK	2	09.00	17.40	MH	N							
TARRYTOWN NY	2		2.	MH	N							

SLUDGE INCINERATION STUDY DATA

FACIITY	REGION	DESIGN FLOW (MGD)	ACTUAL FLOW (MGD)	SLUDGE HNDLNG TRAIN	OP STATUS	START DATE	SLUDGE CONDITIONING	SLUDGE DEWATERING	HRS/WK	DRY SOLIDS LBS/HR	% DRY SOLIDS	WET MASS LBS/HR
TONAWANDA NY 2 MI CREEK 2	2	35.00	13.70	PW MH VF TC WHB	OP	1978	3 ZIMPRO, 300 PSI 390 DEGF 1 IS STANDBY	3 KOMLINE-SAND, 2 ING-RAND VF 1 OF 5 STANDBY		3200	40.0%	8000
TROY NY RENSSELEAR CSD1	2	24.00	18.33	MH VF	OP							
UTICA NY ONEIDA CTY	2	27.00	26.00	MH C PC	OP							
W. BABYLON NY SOUTHWEST SD #3	2	30.00	30.00	MH VF TC	OP		ZIMPRO					
WATERTOWN NY	2	8.	8.	FBI FP CC HWB	OP	1982	25% LIME 10% FERRIC CHLORIDE	2 EDWARDS & JONES FP 1 IS STANDBY	14	2500	40.0%	6250
WOODLAWN NY WOODLAWN SD	2	00.25	00.21	MH	OP							
AKRON OH	5	75.00	79.	MH VF	OP							

SLUDGE INCINERATION STUDY DATA

FACIITY	REGION	DESIGN FLOW (MGD)	ACTUAL FLOW (MGD)	SLUDGE HNDLNG TRAIN	OP STATUS	START DATE	SLUDGE CONDITIONING	SLUDGE DEWATERING	HRS/WK	DRY SOLIDS LBS/HR	% DRY SOLIDS	WET MASS LBS/HR
CANTON OH	5	44.	25.53	PWD MH VF TC	OP	1971	2 ZIMPRO, 300 PSI 375 DEGF 1 IS STANDBY	4 EIMCO CLOTH VF 2 ARE STANDBY		1333	38.5%	3462
CINCINATTI OH LITTLE MIAMI	5	38.00	27.10	PW MH VF TC WHR	OP	1979	3 ZIMPRO, 300 PSI 390 DEGF 1 IS STANDBY	4 ENVIREX CLOTH VF 2 ARE STANDBY		5500	50.0%	11000
CINCINNATI OH MILL CREEK WWTP	5	120.00	107.	MH VF PCTC NWHR	OP	1973	4 ZIMPRO	EIMCO CLOTH VF, 25 YRS OLD	168	5083	43.5%	11685
CINCINNATI OH MUDDY CREEK	5	15.00	08.10	PW MH VF TC	OP	1971	BSP HEAT TMT					
CLEVELAND OH SOUTHERLY	5	200.	110.00	PW MH VF TC WHB	OP	1980	5 ZIMPRO, 300 PSI 375 DEGF 2 ARE STANDBY	12 EIMCO CLOTH VF 6 ARE STANDBY		22000	45.0%	48888
CLEVELAND OH WESTERLY NE OHIO REGL	5	50.00	35.46	MH C PC NWHR	OP				40		27.5%	
COLUMBUS OH JACKSCN PIKE #1	5	100.00	92.	PWD MH VF PCTC	OP	1968	ZIMPRO					

SLUDGE INCINERATION STUDY DATA

FACIITY	REGION	DESIGN FLOW (MGD)	ACTUAL FLOW (MGD)	SLUDGE HNDLNG TRAIN	OP STATUS	START DATE	SLUDGE CONDITIONING	SLUDGE DEWATERING	HRS/WK	DRY SOLIDS LBS/HR	% DRY SOLIDS	WET MASS LBS/HR
COLUMBUS OH JACKSON PIKE #2	5	50.		MH VF TC	OP		ZIMPRO					
COLUMBUS OH SOUTHERLY	2	100.		PWD MH VF TC	OP	1976	3 ZIMPRO					
EUCLID OH	5	18.00	17.	MH VF	OP							
LORAIN OH BLACK RIVER	5	15.00	13.63	MH	OP							
MASSILLON OH	5	17.00	10.53	MH VF TC	OP		BSP HEAT TMT					
MIDDLEBURG HTS OH	5	02.00	02.04	MH	OP							
MIDDLETOWN OH	5	23.00	19.00	MH VF	OP							

FACIITY	REGION	DESIGN FLOW (MGD)	ACTUAL FLOW (MGD)	SLUDGE HNDLNG TRAIN	OP STATUS	START DATE	SLUDGE CONDITIONING	SLUDGE DEWATERING	HRS/WK	DRY SOLIDS LBS/HR	% DRY SOLIDS	WET MASS LBS/HR
MINERAL RIDGE OH MEANDER CREEK	5	04.00	02.51	MH	OP							
NEWARK OH	5	12.00	10.	PWD MH VF	N	1969						
STEUBENVILLE OH	5	06.00	03.86	MH	N							
WARREN OH	5	13.50	13.61	MH VF	OP							
WILLOUGHBY OH WILL'BY EASTLK	5	10.00	06.87	MH	OP							
YOUNGSTOWN OH	5	50.00	29.	P MH VF	OP	1962			67	1875	30.0%	6250
LAWTON OK	6		6.	PS MH	N	1974						

SLUDGE INCINERATION STUDY DATA

FACILITY	REGION	DESIGN FLOW (MGD)	ACTUAL FLOW (MGD)	SLUDGE HNDLNG TRAIN	OP STATUS	START DATE	SLUDGE CONDITIONING	SLUDGE DEWATERING	HRS/WK	DRY SOLIDS LBS/HR	% DRY SOLIDS	WET MASS LBS/HR
MUSKOGEE OK	6	08.00	04.43	MH VF TC	N		BSP HEAT TMT					
OKLAHOMA CITY OK N CANADIAN	6	40.00	02.23	MH	OP							
TIGARD OR DURHAM REGL	10	20.00	8.	W MH C PC	OP	1974			120	356	22.5%	1582
ABINGTON PA	3	03.91	03.48	MH VF	OP							
AMBRIDGE PA	3	02.56	01.20	MH VF	OP							
APOLLO PA KISKI VLY WPCA	3	07.00	03.56	P MH VF	OP	1973						
BETHLEHEM PA	3	15.50	10.80	MH	OP							

SLUDGE INCINERATION STUDY DATA

FACIITY	REGION	DESIGN FLOW (MGD)	ACTUAL FLOW (MGD)	SLUDGE HNDLNG TRAIN	OP STATUS	START DATE	SLUDGE CONDITIONING	SLUDGE DEWATERING	HRS/WK	DRY SOLIDS LBS/HR	% DRY SOLIDS	WET MASS LBS/HR
BRIDGEPORT PA	3	01.00	00.54	P MH	OP	1964						
CAMP HILL PA LWR ALLEN TWP	3	05.95	02.11	PW MH C	OP	1972						
CHESTER PA DELCORA CHESTER	3	52.00	36.	PW MH VF	OP	1974						
COLMAR PA HATFIELD TWNP	3	04.00	02.07	P MH VF TC	OP	1965						
DOWNINGTON PA DOWNINGTON REGL	3	04.00	03.86	PW FBI C PC	N	1973				1560	22.0%	7090
DURYEA PA LWR LACKAWANNA	3		6.	P MH NWHR	IOP	1973						
ERIE PA ERIE CITY	3	64.00	56.84	PW MH VF WHB	IOP	1973		5 KOMLINE-SANDERSON VF 2 ARE STANDBY		2700	13.5%	20000

SLUDGE INCINERATION STUDY DATA

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FARRELL PA	3	01.75	01.07	MH	OP							
HARLEYSVILLE PA	3	0C.07	00.48	FBI VF	OP							
HARRISBURG PA	3	3C.90	20.30	MH VF TC	OP							
HAZLETON PA	3		6.	PW FBI WHB	OP	1965						
HERSHEY PA DERRY TWNP	3	05.00	01.53	MH VF	N							
JOHNSTOWN PA	3	09.00	08.87	P MH VF	OP	1960			120	490	24.0%	2041
JOHNSTOWN PA JOHNSTOWN	3			MH NWHR	OP	1961			120	2043	24.0%	8512

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KING OF PRUSSIA PA TROUT RUN	3	05.00	04.40	MH VF	OP							
KING OF PRUSSIA PA UPR MARION TWP	3			P FBI WHB	N	1968						
LANSDALE PA UPP GWYN-TOW	3	06.50	02.00	P MH VF	OP	1969						
LEMOYNE PA BORO OF LEMOYNE	3			MH FP PC MWHR	IOP	1973		BELT FILTER PRESS		400	20.0%	2000
MCKEESPORT PA	3	11.50	09.73	MH VF	OP							
MORRISVILLE PA	3	05.60	04.64	PW MH VF	N	1973						
NORRISTOWN PA E NORTWN PLYMTH	3	09.30	04.45	PS MH VF	OP	1968						

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NORTH WALES PA UPR GWYNEDD TWP	3	02.20	01.54	PW FBI VF	OP	1971						
OLD FORGE PA LWR LACKAWANNA	3	06.00	02.10	MH VF	OP							
PHOENIXVILLE PA VALLEY FORGE	3	08.00	05.33	MH VF TC	OP							
PITTSBURGH PA ALCOSAN	3	200.00	167.00	MH VF PCCC WHB	OP	1984	5 TO 10% LIME	7 KOMLINE-SANDERSON BELT FILTER PRESSES		6700	25.0%	26800
RUTHERFORD HTS PA	3			PW MH	N	1971						
SCRANTON PA SCRANTON SA	3	28.00	16.75	MH VF	OP							
SUNBURY PA	3	03.50	02.30	MH VF TC	N							

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TYRONE PA TYRONE BORO	3	09.00	05.92	PW FBI	N	1976				1600	20.0%	8000
W HAZELTON PA GR HAZELTON JSA	3	05.80	05.80	MH VF	OP							
WILKES-BARRE PA WYOMING VLY SA	3	40.00	25.	P MH VF	OP	1967						
WILLOW GROVE PA U MORELD-HTBORO	3	06.60	04.34	MH VF	OP							
YORK PA YORK WPC CTR	3	26.00	16.25	MH VF PCTC WHB	OP	1981	2 BSP, 250 PSI 375 DEGF 1 IS STANDBY	2 EIMCO CLOTH VF	168	938	37.5%	2501
CRANSTON RI	1	11.40	9.	MH WHR	OP	1984						
PROVIDENCE RI FIELDS PT	1	64.00	60.00	PW MH VF	N	1977						

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SMITHFIELD RI	1	03.50	00.82	MH C PC	N							
WOONSOCKET RI	1	16.00	09.03	PW MH VF	OP	1975						
CHARLESTON SC PLUM IS	4	18.00	15.	P MH VF	OP	1969						
COLUMBIA SC METROPOLITAN	4	20.00	22.20	PW MH C	OP	1971						
BRISTOL TN GALLOWAY HILL	4	10.00	08.28	PW MH VF	OP	1971						
CLARKSVILLE TN	4		5.	PW FBI WHB	OP	1964						
ELIZABETHTON TN	4			PW MH	N	1971						

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MARYVILLE TN MARYVILLE REGL	4	07.50	3.	PWD MH VF	OP	1974						
NASHVILLE TN NASHVLE CENTRAL	4	91.00	51.	MH VF	OP							
NASHVILLE TN WHITES CREEK	4	25.00	09.70	MH	OP							
NEWPORT TN	4	04.31	02.30	P MH VF PC	IOP	1978		2 KOM-SAND BELT FILTER PRESSES		63	17.0%	370
HOUSTON TX ALMEDA SIMS	6	20.00	10.76	MH VF TC	OP							
IRVING TX TRINITY RIVER	6	110	100.	PW MH FP CC WHR	N	1976	15% LIME 5% FERRIC CHLORIDE	8 STONE & EDWARDS FILTER PRESSES		500	35.0%	1428
GREENVILLE UT	8	05.29	03.49	MH VFC PC	OP							

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IRVING UT CENTRAL	8	100.00	69.60	MH FP	OP							
PLANO UT PLANO-ROWLTT CR	8	12.00	10.46	MH VF	OP							
RICHARDSON UT FLOYD BRANCH	8	02.25	01.98	MH VF	N							
ALEXANDRIA VA ALEX SAN AUTH	3		25.	MH	OP							
ARLINGTON CTY VA	3	4C.	26.	W MH FP CC WHB	N	1982	15% LIME 5% FERRIC CHLORIDE	4 STONE & EDWARDS FP 2 ARE STANDBY		938	37.5%	2501
BLACKSBURG VA LR STRAUBLES CK	3	06.00	02.80	FBI	OP	1981						
FAIRFAX VA LWB POTOMAC	3	36.00	23.	PW MH VF	OP	1973						

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HOPEWELL VA HOPEWL REG AUTH	3	5C.	40.	PW MH VF TC WHB	OP	1979	3 BSP HEAT TMT	4 EIMCO CLOTH VF 2 ARE STANDBY		2000	25.5%	7843
LORTON VA LOWER POTOMAC	3			MH VF CC NWHR	OP	1970	LIME & FERRIC CHLORIDE		168	4813	17.5%	27502
NEWPORT NEWS VA BOAT HARBOR	3		18.	MH C PC NWHR	OP	1976				2083	4.0%	52075
NORFOLK VA ARMY BASE	3	18.00	13.85	MH C PC NWHR	OP	1976			105	312	22.0%	1418
NORFOLK VA LAMBERTS POINT	3	30.00	28.	MH VF	OP							
VA BEACH VA CHESAPEAKE-ELIZ HAMPTON RDS.	3	24.00	19.12	MH C TC WHB	OP	1977	1 BSP, 180 PSI 385 DEGF	3 SHARPLES CENTRIFUGES 1 IS STANDBY	160	672	28.0%	2400
WILLIAMSBURG VA	3	09.60	6.	MH VF	OP							

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WOODBRIDGE VA POTOMAC RIVER	3	12.0	06.18	MH C PC	OP							
BELLINGHAM WA	10			P MH C	N	1972						
COWLITZ CO. WA	10	10.	6.	MH VF TC	N		1 BSP, 170 PSI 360 DEGF	2 KOMLINE-SANDERSON VF		15000	37.5%	40000
EDMONDS WA	10		4.	P FBI	OP	1967						
LYNWOOD WA	10			P FBI	N	1962				520		
BROOKFIELD WI FOX RIVER	5		10.	PW MH FP NWHR	OP	1974			120	1300	40.0%	3250
DE PERE WI	5	14.20	03.13	S MH FP	OP	1976						

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GREEN BAY WI GREEN BAY MSD	5	52.50	29.	PW MH VF TC WHB	OP	1976	4 ZIMPRO, 350 PSI 380 DEGF 2 ARE STANDBY	4 EIMCO CLOTH VF 2 ARE STANDBY	168	3150	34.5%	9130
MARINETTE WI	5	04.25	03.49	MH VF	N							
MILWAUKEE WI JONES IS	5	185.00	142.20	MH VF	OP							
MILWAUKEE WI S SHORE	5	120.00	72.	MH	N							
MONTGOMERY WI	5	00.50	00.34	MH	OP							
OSHKOSH WI	5	20.00	10.47	PW MH VF TC	N		ZIMPRO					
SHEBOYGAN WI	5			P FBI WHB	N	1967						

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SMITHERS WI	5	00.30	00.14	MH	OP							
ABERDEEN WV	3	04.88	04.83	MH	OP							
BELLINGHAM WV	3	18.00	10.20	MH C PC	OP							
CLARKSBURG WV	3	04.60	04.58	PW MH VF PC MWHR	OP	1973			9	1081	22.0%	4913
EDMONDS WV	3	09.80	05.23	MH VF	OP							
HUNTINGTON WV	3		15.	PW MH	M	1975						
LONGVIEW WV	3	10.00	07.23	MH VF	OP							

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MT VERNON WV	3	02.36	02.17	MH	OP							
MUKILTEO WV	3	00.25	00.08	MH	OP							
ST MARYS WV	3	00.30	00.17	MH	OP							
VANCOUVER WV WESTSIDE	3	12.00	09.80	MH VF	OP							
WHEELING WV	3	25.00	05.64	MH VF	OP							